Sandstone Units of the Lee Formation and Related Strata in Eastern Kentucky

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1151–G

Prepared in cooperation with the Kentucky Geological Survey

Sandstone Units of the Lee Formation and Related Strata in Eastern Kentucky

By CHARLES L. RICE

With a section on

Lee and Breathitt Formations along the northwestern part of the eastern Kentucky coal field

By CHARLES L. RICE *and* GORDON W. WEIR

CONTRIBUTIONS TO THE GEOLOGY OF KENTUCKY

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Descriptions of the Lee Formation with a discussion of related stratigraphic units and the paleogeography of eastern Kentucky and adjoining areas of Early and Middle Pennsylvanian Ages

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SANDSTONE UNITS OF THE LEE FORMATION AND RELATED STRATA IN EASTERN KENTUCKY

By CHARLES L. RICE

ABSTRACT

Most of the Cumberland Plateau region of southeastern Kentucky is underlain by thick sequences of quartzose sandstone which are assigned for the most part to the Lee Formation. Much new information has been gathered about the Lee and related strata as a result of the cooperative mapping program of the U.S. Geological Survey and the Kentucky Geological Survey between 1960 and 1978. This report summarizes the age, lithology, distribution, sedimentary structures, and stratigraphic relations of the sandstone units of the Lee within and between each of three major outcrop belts in Kentucky: Cumberland Mountain, Pine Mountain, and the Pottsville Escarpment area.

The Lee Formation generally has been regarded as Early Pennsylvanian in age and separated from Mississippian strata in Kentucky by an unconformity. However, lithostratigraphic units included in the formation as presently defined are broadly time-transgressive and range in age from Late Mississippian in parts of the Cumberland Mountain outcrop belt to Middle Pennsylvanian in the Pottsville Escarpment area. Members of the Lee intertongue with and grade into the underlying Pennington Formation and overlying Breathitt Formation. Sandstone and conglomeratic sandstone members of the Lee of Mississippian age found only in parts of the Cumberland overthrust sheet are closely associated with marine rocks; Pennsylvanian members are mostly associated with continental coal-bearing strata.

Sandstone members of the Lee are mostly quartz rich and range from more than 90 percent to more than 99 percent quartz. They are relatively coarse grained, commonly pebbly, and in places conglomeratic. The units are southwest-trending linear or broadly lobate bodies.

The Lee Formation is as much as 1,500 ft thick in the type area in Cumberland Mountain where it has been divided into eight members. The Pinnacle Overlook, Chadwell, White Rocks Sandstone, Middlesboro, Bee Rock Sandstone, and Naese Sandstone Members are mostly quartzose sandstone and conglomerate. The Dark Ridge and Hensley Members are mostly shale, siltstone, thin-bedded silty sandstone, and coal. The lower three of these members, the Pinnacle Overlook, Chadwell, and White Rocks Sandstone, are assigned to the Upper Mississippian Series because they intertongue with marine reddish or greenish shale and siltstone of the Pennington Formation or equivalent strata that contain a Late Mississippian fauna. The overlying quartzose sandstone members of the Lee commonly have coalified plant remains and impressions of plants and are Early to Middle Pennsylvanian in age; they are generally associated with terrestrial shale and siltstone containing coal beds and pinch out eastward into subgraywacke, siltstone, and shale. Although marine members commonly are bimodal, resultant transport directions for both marine and terrestrial members are southwesterly as determined by crossbedding.

Thickness variations of the Middlesboro Member in the Cumberland overthrust sheet suggest that it represents fills of at least three major southwesterly trending paleovalleys. Thickness variations of the Bee Rock Sandstone Member east of Rocky Face fault and the combined Bee Rock and Naese Sandstone Members west of Rocky Face fault suggest that these members represent fills of at least two major southwesterly trending paleovalleys. East of Rocky Face fault, the Bee Rock is generally the uppermost member of the Lee; west of the fault, the overlying Naese is at the top. The Naese may range in age from Early to Middle Pennsylvanian and is partly or wholly equivalent to the Rockcastle Sandstone member of the Lee Formation in the area of the Pottsville Escarpment. The Mississippian-Pennsylvanian systemic boundary in the area of the Cumberland overthrust sheet in most places has been placed at an unconformity at the base of the Middlesboro Member; locally it is projected at the base of shales of the underlying Dark Ridge Member or equivalent strata in the Pennington Formation.

West of the Cumberland overthrust sheet, the Lee Formation in the Pottsville Escarpment area formerly included all Pennsylvanian strata below the top of the Corbin Sandstone Member. Those strata included, in addition to quartzose sandstone units, carbonaceous shale and siltstone, subgraywacke, and coal beds. Because detailed mapping demonstrated that none of the sandstone units extended through the outcrop area of the escarpment, the Lee was subsequently limited to several thick and persistent quartzose sandstone units: the Livingston Conglomerate Member, the Rockcastle Conglomerate Member, the Corbin Sandstone Member, and the Grayson sandstone bed of Whittington and Ferm (1967). All other intervening and overlying Pennsylvanian strata in the escarpment area are now assigned to the Breathitt Formation.

The Livingston Conglomerate Member, up to 120 ft thick, occupies a paleovalley about 200 ft deep, about 4 mi wide and 20 mi long that was eroded into Mississippian carbonate rocks and shale. The Livingston paleovalley is the largest of four paleovalleys that contain lenses of quartzose sandstone and conglomeratic sandstone. The four channels cross the sub-Pennsylvanian outcrop belt and extend southward to southeastward from the Jessamine Dome of the Cincinnati Arch toward the Appalachian basin. Crossbed dip-directions in the sandstone beds of the channels indicate transport into the Appalachian basin. A sandstone and conglomerate deposit with southwesterly crossbed dip-directions is preserved in an outlier of the Pottsville Escarpment at Pilot Knob, Powell County, 150 to 200 ft stratigraphically below adjacent southeasterly trending channels.

The Rockcastle Conglomerate Member is a quartzose pebbly sandstone with lenses of pebble conglomerate near the base. It is in places more than 200 ft thick and it crops out in a 10- to 20-mi-wide southwest trending belt that parallels the dominant southwesterly current direction indicated by crossbeds. This member tongues to the northwest and pinches out into siltstone and shale, or grades northwestward into very fine-grained ripplebedded sandstone. The southeastern margin of the Rockcastle is not exposed. At its northwestern edge, the Rockcastle is about 150 ft above the Livingston in the subsurface.

The Corbin Sandstone Member is a quartzose sandstone that contains pebbles and lenses of pebbles. It is largely confined to a 10- to 20-mi-wide belt along the Pottsville Escarpment and is locally as much as 250 ft thick. The member pinches out to the northwest in northeastern Kentucky and to the southeast in the central and southern parts of the outcrop belt. Deeply scoured channels at the base of the Corbin trend subparallel to the westerly or southwesterly current directions indicated by the dip directions of crossbeds. Where outcropping, the Corbin lies about 200 to more than 300 ft above the Rockcastle. At the Tennessee border, the Corbin is stratigraphically as much as 700 ft above the eroded top of Mississippian rocks. Pennsylvanian strata beneath the Corbin thin and wedge out to the northeast, so that in the northern part of the outcrop belt, the Corbin is the basal Pennsylvanian unit, locally filling channels cut in the Newman Limestone (Mississippian).

The Grayson sandstone bed of Whittington and Ferm (1967) crops out at the northernmost end of the Lee outcrop belt in northern Kentucky. It is mostly a thin ganisterlike sandstone bed underlying the Bruin coal bed. Locally, it is as much as 70 ft thick and appears to have been deposited in a southwesterly trending channel about 4 mi wide that locally has been eroded into Mississippian strata. Where the Grayson overlies the Corbin Member, it is a few feet to as much as 80 ft above the Corbin.

In late Mississippian time, uplift in the northern part of the central Appalachian orogenic belt exposed deposits of quartzose sandstone and conglomerate to erosion. Coarse clastics from these deposits were transported west and southwest into shallow marine environments where they were reworked by waves and marine currents and were deposited as the Pinnacle Overlook, Chadwell, and White Rocks Sandstone Members of the Lee Formation. As uplift continued into Early Pennsylvanian time, a large area in North America gradually emerged and widespread erosion occurred. Some of this erosion surface has been preserved beneath the overlying Pennsylvanian strata in the eastern part of the United States. The outcrop patterns of Mississippian strata and scanty subsurface data support the following hypothesis: The Appalachian and Eastern Interior basins were separated by a drainage divide that in part coincided with a low northwest-facing cuesta cut in carbonate rocks and extended from western Pennsylvania into central Kentucky. A river system on the northwest side of the cuesta flowed southwestwardly from northern Ohio and Pennsylvania into the Eastern Interior basin in western Kentucky. This river system, herein named Sharon-Brownsville, can be partly reconstructed from Pennsylvanian age channels, channel deposits, and lag deposits.

Early Pennsylvanian uplift to the north and northeast of Kentucky caused an increased volume of sediments, channel cutting, filling of channels, and floods, which, in the Sharon-Brownsville paleovalley, breached to the south and southeast gaps in the Mississippian carbonate cuesta and deepened some valleys by streams that flowed into the Appalachian basin. Eventually major stream captures diverted all the upper part of the Sharon-Brownsville drainage system into the Appalachian basin and into southwest flowing rivers. The major river channels in southeastern Kentucky gradually filled with coarse clastics from northern and northeastern sources. Braided distributaries also spread sediment across most of southeastern Kentucky that resulted in the deposition of the Middlesboro, Bee Rock Sandstone, Naese Sandstone, and Rockcastle Conglomerate Members of the Lee Formation. At the same time, detritus from fine-grained metamorphic rocks exposed in the central Appalachians east of Kentucky was carried increasingly farther west and northwest. By the end of Early Pennsylvanian time, most of the central Appalachian basin was dominated by a delta or a series of coalescing deltas that extended westward and northwestward from the central Appalachians, and coarse clastics from the northern part of the Sharon River were diverted southwestward along valleys paralleling the Irvine-Paint Creek and Kentucky River fault zones in Kentucky. Continued uplift in the Sharon source area and subsidence in the Appalachian basin resulted in deposition of the Corbin Sandstone Member. At this time a large delta plain extended westward across all of eastern Kentucky from the central Appalachians and buried the last remnants of the Mississippian carbonate cuesta in Middle Pennsylvanian time. Continued subsidence led to the spread of marine water from the southwest across much of eastern Kentucky and deposition of a thin marine shale. A brief renewal of the Sharon drainage at a later time resulted in deposition of the Grayson sandstone bed of Whittington and Ferm (1967) at the northeasternmost end of the Lee outcrop belt in northeastern Kentucky.

INTRODUCTION

PURPOSE AND SCOPE OF STUDY

Most of the Cumberland Plateau region (see fig. 2) of southeastern Kentucky is underlain by thick sequences of quartzose sandstone which are time-transgressive and range in age from Late Mississippian to Middle Pennsylvanian. These sandstone units, some of which may be more than 250 ft thick, are largely assigned to the Lee Formation. A few quartzose sandstone units have been assigned to the underlying Pennington Formation and to the overlying Breathitt Formation, both of which intertongue with the Lee. An early unit is the Carter Caves Sandstone of Late Mississippian age. Geologic mapping of eastern Kentucky at a scale of 1:24,000 was conducted by the U.S. Geological Survey in cooperation with the Kentucky Geological Survey and has revealed much new information concerning these sandstone units. The geologic mapping was completed in 1978 and was simultaneously in progress throughout eastern Kentucky from as many as eight field offices. Because of regional stratigraphic and facies variations, a single stratigraphic framework could not be applied everywhere. Also, changing concepts concerning Pennsylvanian stratigraphy resulted in nomenclatural changes and reinterpretation of older data during the project. The objective of this report is to summarize the available data for the members of the Lee Formation and related strata and to describe (1) the lithology, (2) distribution, (3) sedimentary structures, and (4) the stratigraphic relations of the units within and between each of the three major outcrop belts of the Lee: Cumberland Mountain, Pine Mountain, and the Pottsville Escarpment area. Although this report is primarily concerned with rocks of Pennsylvanian age, as indicated above, quartzose sandstone units similar to the Lee (some of which are called Lee) occur in the Upper Mississippian. Indeed, recent investigations suggest that some members of the Lee that have traditionally been assigned to the Lower Pennsylvanian are probably Upper Mississippian in age. All Mississippian sandstone units are associated with marine rocks and should be studied in the context of the strata that enclose them. A detailed study of Upper Mississippian rocks is beyond the scope of this report; however, those Mississippian units that have been termed Lee or are otherwise related to the Lee will be described in appropriate detail.

A fifth objective of this report is to discuss the depositional environments of the sandstone units. Some geologists have suggested, particularly in recent years, that the sandstone units were deposited in near-shore marine environments and represent beach or barrier-bar deposits because of their mineralogical and textural maturity. This report proposes a fluvial model for parts of the central Appalachian and Eastern Interior basins to account for deposition of the quartzose sandstone units of Early and Middle Pennsylvanian age.

The report is based primarily on 222 U.S. Geological Survey Geologic Quadrangle Map (GQ Map) reports, which cover all or parts of 246 quadrangles, that were published from 1961 to the end of the project. Figure 1 is an index map showing the maps covered by the report. All of the quadrangles contain Lee rocks or equivalent strata; in most, these rocks are at the surface. The report also uses unpublished data from the field notes of more than 120 geologists (see table 1) who mapped the area. Some data, particularly concerning the sedimentology and petrology of the sandstone units, are from published geologic reports other than the maps and from many unpublished theses.

Terms used in the text to describe sandstones are

Quartzose sandstone—Sandstone composed of more than 90 percent quartz, commonly about 95 percent. The sandstone contains little or no silt- or clay-size matrix. The terms quartz arenite, orthoquartzite, "clean" sandstone, and Lee-type sandstone are used to describe the same rocks.

Subgraywacke—Sandstone composed of about 65 percent quartz, minor amounts of feldspar, mica, rock fragments, and dark minerals, and about 10 percent silt- or clay-size matrix. The adjective "dirty" has commonly been used to describe this type of sandstone.

PREVIOUS WORK

Strata of the Pennington and Lee Formations in Kentucky were first investigated by Campbell (1893). He named both formations from areas in Virginia near the Kentucky border. Subsequently, Campbell (1898 a, b) described the Pennington and Lee near the Pottsville Escarpment in south-central Kentucky and named and mapped several members of the Lee. In these latter reports, Campbell introduced the name Breathitt Formation for strata overlying the Lee. In their investigations of the Cumberland Gap coal field in southeastern Kentucky, Ashley and Glenn (1906) named the Naese Sandstone Member of the Lee Formation and divided the overlying strata into five formations which were later included in the Breathitt Group by Englund and others (1963, p. 15). A. M. Miller (1910) studied the coal beds in areas along the Pottsville Escarpment and described numerous sections including Mississippian rocks and the overlying Lee and Breathitt strata. Equivalent Pennsylvanian strata were described by Phalen (1912) in northeastern Kentucky.

Englund and Smith (1960) and Englund and De Laney (1966) described the intertonguing relations of the Pennington and Lee Formations in southwestern Virginia. M. S. Miller (1974) studied those rocks in the subsurface of southwestern Virginia and adjacent parts of Kentucky. Englund and Windolph (1971) mapped and described a "Lee-type" sandstone (Carter Caves Sandstone) in the Upper Mississippian rocks of northeastern Kentucky. Rice and Haney (1980) summarized data and ideas concerning the nature of the Mississippian-Pennsylvanian systemic boundary along the Pottsville Escarpment in Kentucky.

Regional and interregional studies of Pennsylvanian rocks by Wanless (1939, 1946, and 1975a) included many descriptions of measured sections from Kentucky. In investigations of sources of basal Pennsylvanian sediments in the Eastern Interior basin, Potter and Siever (1956 a, b) and Siever and Potter (1956) discussed the petrology, trace minerals, and current directions of sedimentary structures of the basal Pennsylvanian sandstone units in the Appalachian basin. General summaries of the stratigraphy of Mississippian and Pennsylvanian rocks for Kentucky were made by Rice and others (1979) and for Virginia by Englund (1979).

GEOGRAPHIC SETTING

The Pennsylvanian rocks of eastern Kentucky crop out and underlie an area of about 10,500 mi^2—a part of the Appalachian Plateau here called the Cumberland Plateau (fig. 2). The Cumberland Plateau is an intricately dissected upland of sharp ridges and V-shaped valleys. The area is borderd on the west by the Pottsville Escarpment which is made up of a series of hills capped by cliffs of resistant Pennsylvanian sandstone. The escarpment is as much as 700 ft high at the southern border of the State, but relief diminishes northeastward. Sandstone of the Lee Formation of Pennsylvanian age is overlain by less resistant shale and locally forms broad uplands of low relief along the

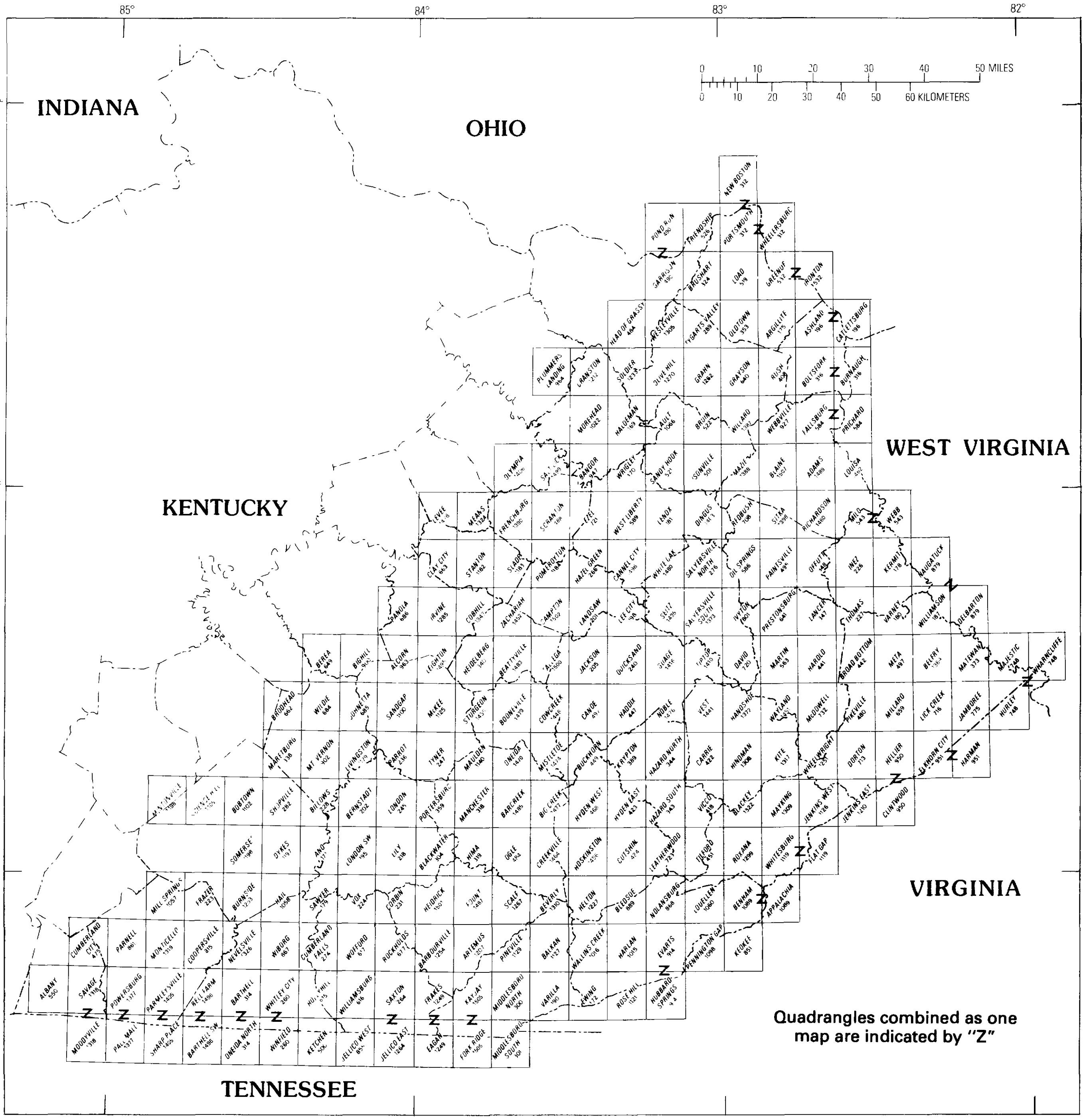


FIGURE 1.—Index of U.S. Geological Survey 7½-min. quadrangle maps of area in eastern Kentucky underlain by Pennsylvanian strata. County names are shown in figure 3.

west-central and southwest border of the plateau. The area is bordered on the southeast by two east-northeast-trending ridges, Pine and Cumberland Mountains, whose crests are underlain by dipping sandstone beds of Late Mississippian or Early Pennsylvanian age. The highest mountains in Kentucky are between Pine and Cumberland Mountains near Cumberland, Ky. (see fig. 3). The area extends southward into Tennessee and northeastward into Ohio and West Virginia.

Five rivers tributary to the Ohio River drain the area; these are the Cumberland, Kentucky, Licking, and the Big and Little Sandy Rivers. Three of these

TABLE 1.—*List of U.S. Geologic Survey Geologic Quadrangle (GQ) Maps for Eastern Kentucky. Location of maps shown in figure 1.*

[All GQ's are at the scale of 1:24,000]

Quadrangle	GQ Number	Date of Publication	Author
Adams, Ky	1489	1978	Ward, D. E.
Albany, Ky	550	1966	Lewis, R. Q., Sr., and Thaden, R. E.
Alcorn, Ky	963	1972	Rice, C. L.
Ano, Ky	171	1962	Stager, H. K.
Appalachia (Kentucky part combined with Benham)	1059	1973	Froelich, A. J., and Stone, B. D.
Argillite, Ky	175	1962	Sheppard, R. A., and Ferm, J. C.
Artemus, Ky	1207	1974	Rice, D. D.
Ashland, Ky-Ohio (includes Kentucky part of Catlettsburg)	196	1963	Sharps, J. A., and Ferm, J. C.
Ault, Ky	1066	1973	Englund, K. J.
Balkan, Ky	1127	1973	Froelich, A. J., and Tazelaar, J. F.
Bangor, Ky	947	1971	Hylbert, D. K., and Philley, J. C.
Barbourville, Ky	1254	1975	Newell, W. L.
Barcreek, Ky	1485	1978	Taylor, R. A.
Barthell, Ky. (includes Kentucky part of Oneida North)	314	1964	Pomerene, J. B.
Barthell SW (Kentucky part combined with Bell Farm)	1496	1978	Smith, J. H.
Beattyville, Ky	1483	1978	Weir, G. W.
Belfry, Ky	1369	1977	Rice, C. L., Ping, R. G., and Barr, J. S.
Bell Farm, Ky. (includes Kentucky part of Barthell SW)	1496	1978	Smith, J. H.
Benham, Ky. (includes Kentucky part of Appalachia)	1059	1973	Froelich, A. J., and Stone, B. D.
Berea, Ky	649	1967	Weir, G. W.
Bernstadt, Ky	202	1963	Hatch, N. L., Jr.
Beverly, Ky	1310	1976	Weis, P. L., and Rice. C. L.
Big Creek, Ky	1477	1978	Lewis, R. Q., Sr., and Hansen, D. E.
Bighill, Ky	900	1971	Weir, G. W., Lee, K. Y., and Cassity, P. E.
Billows, Ky	228	1963	Hatch, N. L., Jr.
Blackey, Ky	1322	1976	Waldrop, H. W.
Blackwater, Ky	304	1964	Stager, H. K.
Blaine, Ky	1507	1978	Pillmore, C. L., and Connor, C. W.
Bledsoe, Ky	889	1971	Csejtey, Bela, Jr.
Bobtown, Ky	1102	1973	Lewis, R. Q., Sr., Taylor, A. R., and Weir, G. W.
Boltsfork, Ky. (includes Kentucky part of Burnaugh)	316	1964	Spencer, F. D.
Booneville, Ky	1479	1978	Weir, G. W.
Broad Bottom, Ky	442	1965	Alvord, D. C.
Brodhead, Ky	662	1967	Gualtieri, J. L.
Bruin, Ky	522	1966	Englund, K. J., and DeLaney, A. O.
Brushart, Ky	324	1964	Denny, C. S.

TABLE 1.—*List of U.S. Geologic Survey Geologic Quadrangle (GQ) Maps for Eastern Kentucky. Location of maps shown in figure 1.—Continued*

Quadrangle	GQ Number	Date of Publication	Author
Buckhorn, Ky	1449	1978	Danilchik, Walter, and Lewis, R. Q., Sr.
Burnaugh (Kentucky part combined with Boltsfork)	316	1964	Spencer, F. D.
Burnside, Ky	1253	1975	Taylor, A. R., Lewis, R. Q., Sr. and Smith, J. H.
Campton, Ky	1502	1978	Coskren, T. D., and Hoge, H. P.
Cannel City, Ky	1498	1978	Sable, E. G.
Canoe, Ky	1497	1978	Hinrichs, E. N.
Carrie, Ky	422	1965	Seiders, V. M.
Catlettsburg (Kentucky part combined with Ashland)	196	1963	Sharps, J. A., and Ferm, J. C.
Clay City, Ky	663	1967	Simmons, G. C.
Clintwood (Kentucky part combined with Hellier)	950	1971	Alvord, D. C.
Cobhill, Ky	1347	1976	Haney, D. C.
Coopersville, Ky	1315	1976	Lewis, R. Q., Sr., and Taylor, A. R.
Corbin, Ky	231	1963	Puffett, W. P.
Cowcreek, Ky	1448	1978	Outerbridge, W. F.
Cranston, Ky	1212	1975	Philley, J. C., Hylbert, D. K., and Hoge, H. P.
Creekville, Ky	1464	1978	Bryant, Bruce
Cumberland City, Ky	475	1965	Lewis, R. Q., Sr., and Thaden, R. E.
Cumberland Falls, Ky	274	1963	Smith, J. H.
Cutshin, Ky	1424	1977	Ping, R. G.
David, Ky	720	1968	Outerbridge, W. F.
Delbarton (Kentucky part combined with Kentucky part of Naugatuck)	879	1971	Alvord, D. C.
Dingus, Ky	1463	1978	Outerbridge, W. F.
Dorton, Ky	713	1968	Barr, J. L., and Arndt, H. H.
Dykes, Ky	1197	1974	Smith, J. H.
Eagan (Kentucky part combined with Frakes)	1249	1975	Newell, W. L.
Elkhorn City, Ky.-Va. (includes Kentucky part of Harman)	951	1972	Alvord, D. C., and Miller, R. L.
Evarts, Ky.-Va. (includes Kentucky part of Hubbard Springs)	914	1974	Tazelaar, J. F., and Newell, W. L.
Ewing, Ky.-Va.	172	1961	Englund, K. J., Smith, H. L., Harris, L. D., and Stephens, J. G.
Ezel, Ky	721	1968	Pipiringos, G. N., Bergman, S. C., and Trent, V. A.
Fallsburg, Ky. (includes Kentucky part of Prichard)	584	1967	Sharps, J. A.
Flat Gap (Kentucky part combined with Whitesburg)	1119	1973	Rice, C. L., and Wolcott, D. E.

TABLE 1.—*List of U.S. Geologic Survey Geologic Quadrangle (GQ) Maps for Eastern Kentucky. Location of maps shown in figure 1.—Continued*

Quadrangle	GQ Number	Date of Publication	Author
Fork Ridge (Kentucky part combined with Kayjay)	1505	1978	Rice, C. L., and Maughan, E. K.
Fount, Ky	1487	1978	Ping, R. G., and Sergeant, R. E.
Frakes, Ky. (includes Kentucky part of Eagan)	1249	1975	Newell, W. L.
Frazer Ky	1223	1975	Lewis, R. Q., Sr.
Frenchburg, Ky	1390	1977	Hoge, H. P.
Friendship, Ky	526	1966	Erickson, R. L.
Garrison, Ky. (includes Kentucky part of Pond Run)	1490	1978	Chaplin, J. R., and Mason, C. E.
Grahn, Ky	1262	1976	Englund, K. J.
Grayson, Ky	640	1967	Whittington, C. L., and Ferm, J. C.
Greenup, Ky. (includes Kentucky part of Ironton)	532	1966	Dobrovolny, E., Ferm, J. C., and Eroskay, S. O.
Guage, Ky	1416	1977	Lee, K. Y., Danilchik, Walter, and Rice, C. L.
Haddix, Ky	447	1965	Mixon, R. B.
Hail, Ky	1058	1973	Smith, J. H., Pomerene, J. B., and Ping, R. G.
Haldeman, Ky	169	1961	Patterson, S. H., and Hoaterman, J. W.
Handshoe, Ky	1372	1977	Danilchik, Walter
Harlan, Ky	1015	1972	Froelich, A. J., and McKay, E. J.
Harman (Kentucky part combined with Elkhorn City)	951	1972	Alvord, D. C., and Miller, R. L.
Harold, Ky	441	1965	Rice, C. L.
Hazard North, Ky	334	1964	Seiders, V. M.
Hazard South, Ky	343	1964	Puffett, W. P.
Hazel Green, Ky	266	1963	Cashion, W.B.
Head of Grassy, Ky	484	1966	Morris, R. H.
Heidelberg, Ky	1340	1977	Black, D. F. B.
Heidrick, Ky	1501	1978	Trimble, D. E., and Smith, J. H.
Hellier, Ky.-Va.	950	1971	Alvord, D. C.
Helton, Ky	1227	1975	Rice, D. D.
Hima, Ky	319	1964	Reeves, R. C.
Hindman, Ky	1308	1976	Danilchik, Walter
Hollyhill, Ky	615	1967	Loney, R. A.
Hoskinston, Ky	1456	1978	Taylor, A. R.
Hubbard Springs (Kentucky part combined with Evarts)	914	1974	Tazelaar, J. F., and Newell, W. L.
Hurley (Kentucky part combined with parts of Majestic and Wharncliffe)	748	1968	Outerbridge, W. F.
Hyden East, Ky	423	1965	Prostka, H. J.
Hyden West, Ky	1468	1978	Lewis, R. Q., Sr.
Inez, Ky	226	1963	Outerbridge, W. F.

TABLE 1.—*List of U.S. Geologic Survey Geologic Quadrangle (GQ) Maps for Eastern Kentucky. Location of maps shown in figure 1.—Continued*

Quadrangle	GQ Number	Date of Publication	Author
Ironton (Kentucky part combined with Kentucky part of Greenup)	532	1966	Dobrovolny, E., Ferm, J. C., and Eroskay, S. O.
Irvine, Ky	1285	1976	Hoge, H. P., Wigley, P. B., and Shawe, F. R.
Isonville, Ky	501	1966	Englund, K. J., and DeLaney, A. O.
Ivyton, Ky	801	1969	Rice, C. L.
Jackson, Ky	205	1963	Prichard, G. E., and Johnston, J. E.
Jamboree, Ky	775	1968	Outerbridge, W. F., and Van Vloten, Roger
Jellico East (Kentucky part combined with Saxton)	1264	1975	Rice, C. L., and Newell, W. L.
Jellico West, Tenn.-Ky.	855	1969	Englund, K. J.
Jenkins East, Ky	1210	1974	Wolcott, D. E.
Jenkins West, Ky.-Va.	1126	1973	Rice, C. L.
Johnetta, Ky	685	1968	Gualtieri, J. L.
Kayjay, Ky. (includes Kentucky part of Fork Ridge)	1505	1978	Rice, C. L., and Maughan, E. K.
Keokee, Va.-Ky.	851	1971	Miller, R. L., and Roen, J. B.
Kermit, Ky	178	1962	Huddle, J. W., and Englund, K. J.
Ketchen, Tenn.-Ky.	500	1966	Englund, K. J.
Kite, Ky	1317	1976	Hinrichs, E. N., and Rice, C. L.
Krypton, Ky	389	1965	Mixon, R. B.
Lancer, Ky	347	1964	Rice, C. L., and Johnston, J. E.
Landsaw, Ky	201	1963	Hansen, W. R., and Johnston, J. E.
Leatherwood, Ky	723	1968	Prostka, H. J., and Seiders, V. M.
Lee City, Ky	198	1963	Post, E. V., and Johnston, J. E.
Leighton, Ky	1495	1978	Haney, D. C., and Rice, C. L.
Lenox, Ky	181	1962	Johnston, J. E.
Levee, Ky	1478	1978	McDowell, R. C.
Lick Creek, Ky	716	1969	McKay, E. J., and Alvord, D. C.
Lily, Ky	218	1963	Stager, H. K.
Livingston, Ky	1179	1974	Brown, W. R., and Osolnik, M. J.
Load, Ky	519	1966	Sharps, J. A.
London, Ky	245	1963	Hatch, N. L., Jr.
London SW, Ky	195	1963	Stager, H. K.
Louellen, Ky	1060	1973	Froelich, A. J.
Louisa, Ky	1462	1978	Connor, C. W., and Flores, R. M.
Majestic, Ky. (includes Kentucky parts of Hurley and Wharncliffe)	748	1968	Outerbridge, W. F.
Manchester, Ky	318	1964	Finnell, T. L.
Maretburg, Ky	338	1965	Schlanger, S. O.
Martin, Ky	563	1966	Rice, C. L.
Matewan, Ky	373	1965	Trent, V. A.

TABLE 1.—*List of U.S. Geologic Survey Geologic Quadrangle (GQ) Maps for Eastern Kentucky. Location of maps shown in figure 1.—Continued*

Quadrangle	GQ Number	Date of Publication	Author
Maulden, Ky	1140	1974	Lee, K. Y., and Jones, C. L.
Mayking, Ky	1309	1976	Rice, C. L.
Mazie, Ky	1388	1977	Outerbridge, W. F.
McDowell, Ky	732	1968	Rice, C. L.
McKee, Ky	1125	1973	Weir, G. W., and Mumma, M. D.
Means, Ky	1324	1976	Weir, G. W.
Meta, Ky	497	1966	Wolcott, D. E., and Jenkins, E. C.
Middlesboro North, Ky	300	1964	Englund, K. J., Roen, J. B., and DeLaney, A. O.
Middlesboro South, Tenn.-Va.	301	1964	Englund, K. J.
Millard, Ky	659	1967	Jenkins, E. C.
Mill Springs, Ky	1057	1972	Lewis, R. Q., Sr.
Milo, Ky. (includes Kentucky part of Webb)	543	1966	Jenkins, E. C.
Mintonville, Ky	1198	1974	Lewis, R. Q., Sr., and Taylor, A. R.
Mistletoe, Ky	1474	1978	Volckmann, R. P., and Leo, G. W.
Monticello, Ky	1319	1976	Taylor, A. R.
Moodyville (Kentucky part combined with Savage)	1318	1976	Lewis, R. Q., Sr.
Morehead, Ky	1022	1972	Hoge, H. P., and Chaplin, J. R.
Mount Vernon, Ky	902	1971	Schlanger, S. O., and Weir, G. W.
Naugatuck, Ky. (includes Kentucky part of Delbarton)	879	1971	Alvord, D. C.
Nevelsville, Ky	1326	1976	Smith, J. H.
New Boston (Kentucky part combined with Kentucky part of Portsmouth)	312	1964	Sheppard, R. A.
Noble, Ky	1476	1978	Hinrichs, E. N.
Nolansburg, Ky	868	1970	Csejtey, Bela, Jr.
Offutt, Ky	348	1964	Outerbridge, W. F.
Ogle, Ky	1484	1978	Ping, R. G., and Sergeant, R. E.
Oil Springs, Ky	586	1967	Outerbridge, W. F.
Oldtown, Ky	353	1965	Whittington, C. L., and Ferm, J. C.
Olive Hill, Ky	1270	1975	Englund, K. J., and Windolph, J. F.
Olympia, Ky	1406	1977	McDowell, R. C., and Weir, G. W.
Oneida, Ky	1470	1978	Rice, C. L., and Lee, K. Y.
Oneida North (Kentucky part combined with Barthell)	314	1964	Pomerene, J. B.
Paintsville, Ky	495	1966	Outerbridge, W. F.
Pall Mall (Kentucky part combined with Powersburg)	1377	1977	Lewis, R. Q., Sr.
Panola, Ky	686	1968	Greene, R. C.
Parmleysville, Ky. (includes Kentucky part of Sharp Place)	1405	1977	Taylor, A. R.

TABLE 1.—*List of U.S. Geologic Survey Geologic Quadrangle (GQ) Maps for Eastern Kentucky. Location of maps shown in figure 1.—Continued*

Quadrangle	GQ Number	Date of Publication	Author
Parnell, Ky	861	1970	Lewis, R. Q., Sr., and Luft, S. J.
Parrot, Ky	236	1963	Crowder, D. F.
Pennington Gap, Va.-Ky.	1098	1973	Miller, R. L., and Roen, J. B.
Pikeville, Ky	480	1965	Alvord, D. C., and Holbrook, C. E.
Pineville, Ky	1129	1974	Froelich, A. J., and Tazelaar, J. F.
Plummers Landing, Ky	964	1971	McDowell, R. C., Peck, J. H., and Mytton, J. W.
Pomeroyton, Ky	1184	1974	Weir, G. W., and Richards, P. W.
Pond Run (Kentucky part combined with Kentucky part of Garrison)	1490	1978	Chaplin, J. R., and Mason, C. E.
Portersburg, Ky	359	1964	Pomerene, J. B.
Portsmouth, Ky. (includes Kentucky part of Wheelersburg and New Boston)	312	1964	Sheppard, R. A.
Powersburg, Ky. (includes Kentucky part of Pall Mall)	1377	1977	Lewis, R. Q., Sr.
Prestonsburg, Ky	641	1967	Rice, C. L.
Prichard (Kentucky part combined with Fallsburg)	584	1967	Sharps, J. A.
Quicksand, Ky	240	1963	Johnston, J. E., and Donnell, J. R.
Redbush, Ky	708	1968	Rice, C. L.
Richardson, Ky	1460	1978	Sanchez, J. D., Alvord, D. C., and Hayes, P. T.
Rockholds, Ky	677	1967	Smith, J. H.
Rose Hill, Ky	1121	1973	Maughan, E. K., and Tazelaar, J. F.
Roxana, Ky	1299	1976	Maughan, E. K.
Rush, Ky	408	1965	Carlson, J. E.
Salt Lick, Ky	1499	1978	Philley, J. C.
Salyersville North, Ky	276	1964	Adkison, W. L., and Johnston, J. E.
Salyersville South, Ky	1373	1977	Spengler, R. W.
Sandgap, Ky	1100	1973	Gualtieri, J. L.
Sandy Hook, Ky	521	1966	Englund, K. J., and DeLaney, A. O.
Savage, Ky. (includes Kentucky part of Moodyville)	1318	1976	Lewis, R. Q., Sr.
Sawyer, Ky	179	1962	Puffett, W. P.
Saxton, Ky. (includes Kentucky part of Jellico East)	1264	1975	Rice, C. L., and Newell, W. L.
Scalf, Ky	1267	1975	Weis, P. L.
Science Hill, Ky	1105	1973	Taylor, A. R., and Lewis, R. Q., Sr.
Scranton, Ky	1488	1978	Haney, D. C., and Hester, N. C.
Seitz, Ky	1435	1978	Spengler, R. W.

TABLE 1.—*List of U.S. Geologic Survey Geologic Quadrangle (GQ) Maps for Eastern Kentucky. Location of maps shown in figure 1.—Continued*

Quadrangle	GQ Number	Date of Publication	Author
Sharp Place (Kentucky part combined with Parmleysville)	1405	1977	Taylor, A. R.
Shopville, Ky	282	1964	Hatch, N. L., Jr.
Sitka, Ky	1398	1977	Hayes, P. T.
Slade, Ky	1183	1974	Weir, G. W.
Soldier, Ky	1233	1975	Philley, J. C., Hylbert, D. K., and Hoge, H. P.
Somerset, Ky	1196	1974	Lewis, R. Q., Sr.
Stanton, Ky	1182	1974	Weir, G. W.
Sturgeon, Ky	1455	1978	Weir, G. W.
Tallega, Ky	1500	1978	Black, D. F. B.
Thomas, Ky	227	1963	Rice, C. L.
Tilford, Ky	451	1965	Puffett, W. P.
Tiptop, Ky	1410	1977	Danilchik, Walter
Tygarts Valley, Ky	289	1964	Sheppard, R. A.
Tyner, Ky	247	1963	Snyder, G. L.
Varilla, Ky.-Va.	190	1963	Englund, K. J., Landis, E. R., and Smith, H. L.
Varney, Ky	180	1962	Huddle, J. W., and Englund, K. J.
Vest, Ky	1441	1978	Danilchik, Walter, and Waldrop, H. W.
Vicco, Ky	418	1965	Puffett, W. P.
Vox, Ky	224	1963	Puffett, W. P.
Wallins Creek, Ky	1016	1972	Froelich, A. J.
Wayland, Ky	1451	1978	Hinrichs, E. N., and Ping, R. G.
Webb (Kentucky part combined with Milo)	543	1966	Jenkins, E. C.
Webbville, Ky	927	1971	Carlson, J. E.
Wesleyville, Ky	1305	1976	Philley, J. C., and Chaplin, J. R.
West Liberty, Ky	589	1967	Englund, K. J., Huddle, J. W., and DeLaney, A. O.
Wharncliffe (Kentucky part combined with Kentucky parts of Majestic and Hurley)	748	1968	Outerbridge, W. F.
Wheelersburg (Kentucky part combined with Kentucky part of Portsmouth)	312	1964	Sheppard, R. A.
Wheelwright, Ky	1251	1975	Outerbridge, W. F.
White Oak, Ky	1480	1978	Sable, E. G.
Whitesburg, Ky.-Va. (includes Kentucky part of Flat Gap)	1119	1973	Rice, C. L., and Wolcott, D. E.
Whitley City, Ky. (includes Kentucky part of Winfield)	260	1964	Pomerene, J. B.
Wiborg, Ky	867	1970	Smith, J. H.
Wildie, Ky	684	1968	Gualtieri, J. L.
Willard, Ky	1387	1977	Brown, W. R.
Williamsburg, Ky	616	1967	Tabor, R. W.
Williamson, Ky	187	1962	Alvord, D. C., and Trent, V. A.
Winfield (Kentucky part combined with Whitley City)	260	1964	Pomerene, J. B.
Wofford, Ky	617	1967	Smith, J. H.
Wrigley, Ky	170	1961	Hosterman, J. W., and Patterson, S. H.
Zachariah, Ky	1452	1978	Black, D. F. B.

rivers have their headwaters generally in or near Pine and Cumberland Mountains where local relief is as much as 2,300 ft. The flood plains of the rivers have frequent winter and early spring flooding. Dams designed to control floods on the larger streams and rivers have empounded large reservoirs and increased the water resources of the area.

Eastern Kentucky has an annual rainfall that ranges from about 40 to 60 in. and has a mean annual temperature of about 58°F. Temperatures rarely exceed 100°F or drop below 0°F. The climate supports a dense forest of broadleaf deciduous trees and shrubs (Braun, 1950). The area has a moderately sparse population, and most inhabitants live along narrow stream valleys in small cities and towns. The major industry in eastern Kentucky is coal mining. Other important industries are gas and oil production, logging, and farming.

Many roads provide good access to most of eastern Kentucky (fig. 3). Extensive and high road cuts along the primary State and Federal highways that cross the area expose a nearly complete Pennsylvanian stratigraphic section. Lee rocks and equivalent strata are best exposed along U.S. Interstate Highways I-75 and I-64 as well as those roads that cross Pine and Cumberland Mountains, and the Pottsville Escarpment.

ACKNOWLEDGMENTS

This report has been prepared in cooperation with the Kentucky Geological Survey which has provided the author with office space at its headquarters in Lexington and with a field vehicle for reconnaissance work. Gordon W. Weir gathered and compiled much of the crossbed data reported for the areas along the northwestern part of the eastern Kentucky coal field and compiled the maps related to the Livingston Conglomerate and Corbin Sandstone Members of the Lee Formation. William F. Outerbridge assisted in the compilation of the geologic map of the sub-Pennsylvanian surface.

GEOLOGIC SETTING

Strata of Pennsylvanian age overlie rocks of Mississippian age in eastern Kentucky. The boundary be-

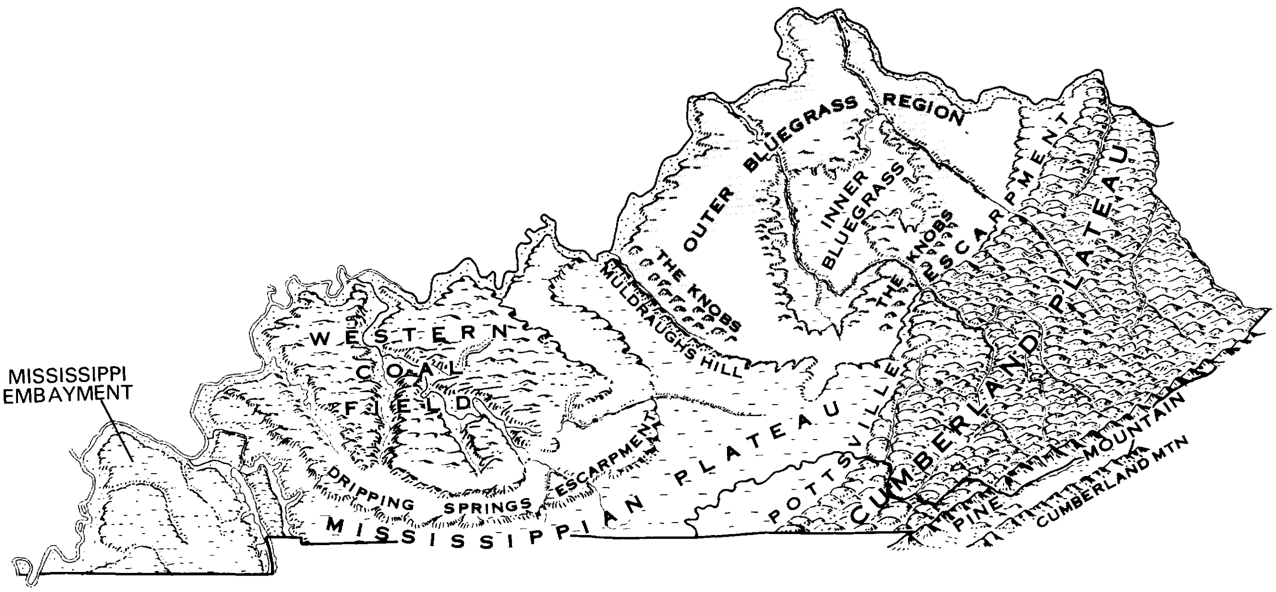


FIGURE 2.—Physiographic diagram of Kentucky (Lobeck, 1929). Pennsylvanian strata underlie the Cumberland Plateau and the Western Coal Field. Other physiographic regions are the Blue Grass region underlain by Ordovician, Silurian, and Devonian rocks; the Knobs region, a narrow belt of conical hills, or knobs, consisting of Lower Mississippian (Osagean) shale and siltstone which are around the outer border of the Blue Grass region; the Mississippian Plateau region, underlain largely by Upper Mississippian carbonate units and divided by the Dripping Springs Escarpment, an east- and south-facing ridge generally capped by the Big Clifty Sandstone Member of the Golconda Formation (Chesterian); and the Mississippian Embayment region where Cretaceous and Tertiary sedimentary deposits rest on Paleozoic rocks. The Pottsville Escarpment borders the Cumberland Plateau on the northwest and is capped by Lower-to-Middle Pennsylvanian sandstone. Muldraughs Hill is a northeast-facing limestone-capped escarpment bordering the Mississippian Plateau region.

tween the systems is generally recognized in most of eastern Kentucky as an unconformity that is more strongly marked toward the north and northwest; in southeasternmost Kentucky in parts of the Cumberland overthrust sheet, identification of the systemic boundary has been hindered by poor exposures and by lack of biostratigraphic data. The underlying Mississippian rocks range in age from middle Osagean in northeastern Kentucky to youngest Chesterian along Pine and Cumberland Mountains.

The Mississippian rocks range from the relatively deep-water, prodelta terrigenous clastics of the Borden and Grainger Formations upwards through the generally shallow-water shelf carbonates of the Newman Limestone and its equivalents to the shallow-water and lower delta-plain deposits of terrigenous clastics and minor marine carbonates of the Pennington Formation and its equivalents. In northeastern Kentucky, where Pennsylvanian rocks overlie the Borden, the Borden is as much as 600 ft thick and consists largely of greenish-gray shale and siltstone and minor amounts of grayish-red shale. The uppermost member of the Borden Formation is the Renfro. In northeastern Kentucky the Renfro consists of a few feet of dolomite that has been commonly included in the overlying carbonates of the Newman Limestone. These clastics were from the northeast, probably from the Acadian tectonic belts of Northeastern United States and Eastern Canada, and were deposited down a southwesterly dipping regional slope.

Carbonates of the Newman Limestone and its equivalents form a wedge that thickens southeastward. Where these carbonates directly underlie a Pennsylvanian strata in the outcrop belt along the Pottsville Escarpment, they are as much as 300 ft thick and consist largely of massive light-gray fossiliferous limestone. In most of southeastern Kentucky, Pennsylvanian rocks rest on strata commonly identified as Pennington Formation. Equivalent strata consisting largely of shale and siltstone were assigned to the upper member of the Newman Limestone by Englund and Windolph (1971) locally in northeastern Kentucky. These strata thicken southeastward into the Appalachian basin (Wilpolt and Marden, 1959). The Pennington is as much as 250 ft thick along the Pottsville Escarpment and about 850 ft thick at the type section at Pennington Gap, Va., about 4 mi east of Kentucky on Cumberland Mountain. The Pennington consists of grayish-red and greenish-gray

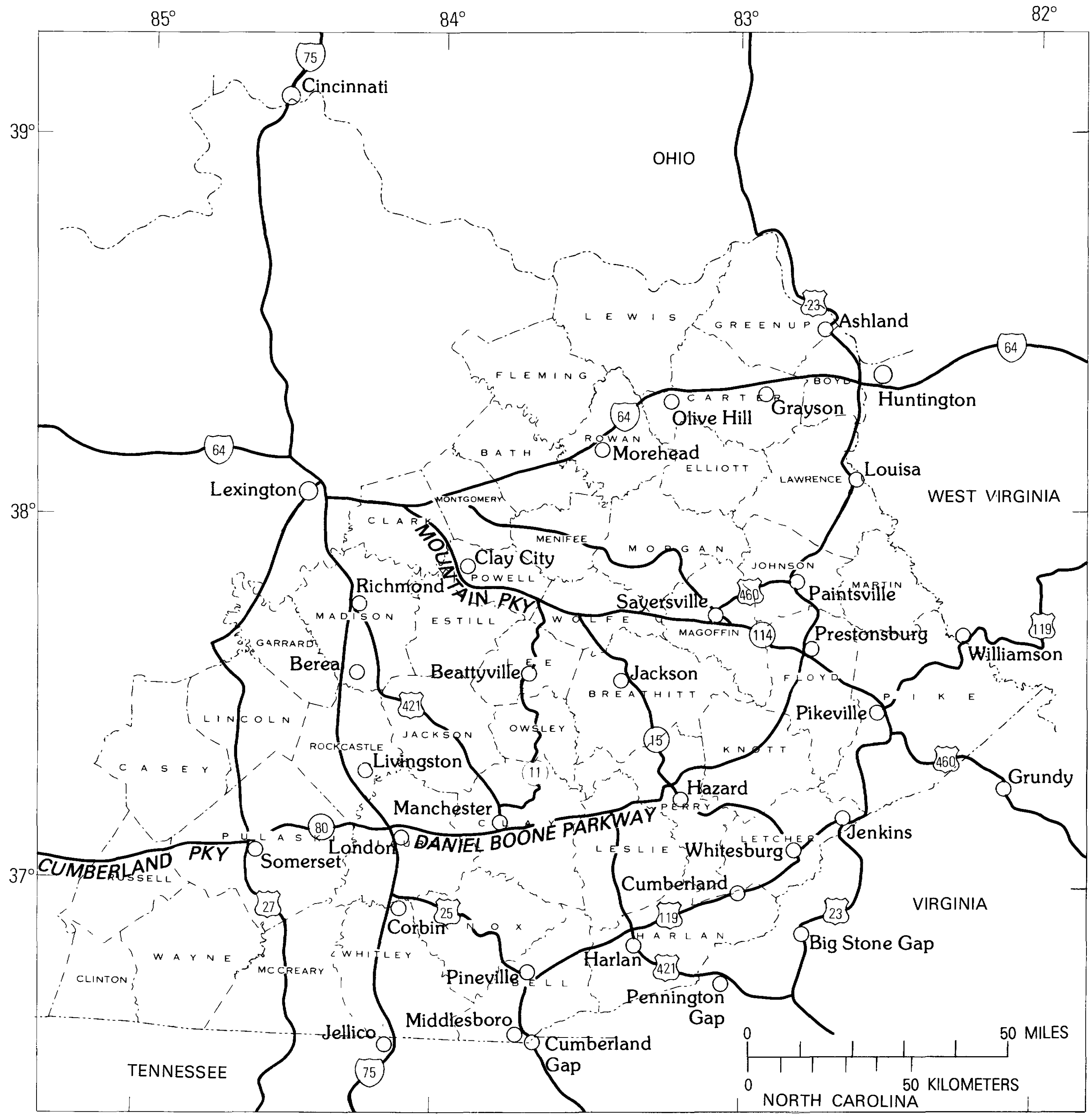


FIGURE 3.—Geographic setting of eastern Kentucky showing counties and major roads and cities.

shale, variegated shale, dark- to medium-gray shale and siltstone, thick beds of light-gray, fine-grained to pebbly sandstone, thin beds of argillaceous limestone and dolomite, and locally a few thin beds of coal. Clastics of the Pennington and equivalent formations were transported westward or southwestward across a prograding delta into and across the Appalachian basin from source areas of metamorphic and sedimentary rocks in and east of the present Piedmont province (de Witt and McGraw, 1979).

In northeastern Kentucky, differential uplift along the axis of the Waverly Arch (Woodward, 1961) produced shoaling as early as middle Meramecian time. This shoaling caused erosion and irregular thinning of carbonate members of the Newman Limestone through middle Chesterian time (Englund, 1972, p. 2108; Dever and others, 1977, p. 15; Ettensohn, 1977, p. 23). According to Pryor and Sable (1974, fig. 9, p. 299), thinning of upper Chesterian strata (Pennington Formation) northerly and westerly on the flanks of the Cincinnati Arch in northern Kentucky suggests emergence of part of that area. The emergence may have been accompanied by a southward tilting of the craton and an upwarping of the Cincinnati Arch (Craig and Connor, 1979, pl. 6A; de Witt and McGraw, 1979, p. 36). Thin coal beds in the Pennington in places along the Pottsville Escarpment (Rice, 1972; Anderson and Hester, 1977, p. 32) and in many localities near the southeast border of Kentucky indicate that as a result of the emergence swamps formed on a low coastal plain and tidal flats.

Uplift and southward tilting of the North American craton in Late Mississippian time resulted in a regional truncation of Mississippian and older strata in areas north of Kentucky. In the northern part of the Illinois basin, Middle Pennsylvanian strata rest on rocks as old as Ordovician. In the northern part of the Appalachian basin (southwestern New York and northwestern Pennsylvania), Early Pennsylvanian strata overlie rocks of Late Devonian age. The Mississippian-Pennsylvanian unconformity extends across Kentucky and implies a possible removal of about 900 ft of Mississippian strata in western Kentucky and about 200 ft in northeastern Kentucky. In southeastern Kentucky, the thickness of missing strata is unknown because detailed information concerning the uppermost Mississippian and the lowermost part of the Pennsylvanian is lacking. Englund and Henry (written commun., 1980) indicate that the systemic boundary is at the unconformity in southeastern Kentucky except in a narrow belt along Cumberland Mountain where the Pocahontas Formation (Early Pennsylvanian age) or equivalent strata conformably overlie the Bluestone Formation (Mississippian) or equivalent strata (see fig. 8). According to Wanless, (1975b, p. 73) the northward and northwestward bevelling of Paleozoic strata in the Late Mississippian resulted in a plain. This plain was later uplifted and was incised by pre-Pennsylvanian streams. In western Kentucky, streams cut subparallel channels as much as 200 ft deep down a southwest-trending paleoslope (Bristol and Howard, 1971). The largest of these, the Brownsville paleovalley originated in the Appalachian area, probably in areas northeast of Ohio and Pennsylvania (Pryor and Potter, 1979, p. 49).

The distribution of the Newman Limestone compiled from GQ Maps along the Pottsville Escarpment (fig. 4) suggests that limestone once extended across much of northeastern Kentucky. Erosion prior to deposition of Pennsylvanian sediments has removed much of the limestone where it was probably thinnest and where it was more exposed to weathering. The resulting limestone subcrop pattern (fig. 4) shows outliers and the irregularly serrated front of a northwest-facing cuesta or cuestas. Figure 5 illustrates in cross section how the regional southeast dip of Mississippian strata into the Appalachian basin and local minor folding resulted in the formation of cuestas prior to burial by Middle Pennsylvanian deposits. Wanless (1975a, p. 24) identified a similar northwest-facing cuesta of equivalent Mississippian limestone in the subsurface in eastern Ohio and western Pennsylvania that occupies a similar position along the northwestern eroded edge of the limestone. Wanless stated that the cuesta was a drainage divide and a regional reconstruction of sub-Pennsylvanian drainage patterns (see fig. 32) suggests that an escarpment, or cuesta extended from western Pennsylvania southwestward into Ohio and central Kentucky and formed the drainage divide between the Appalachian and Eastern Interior basins. The approximate position of the cuesta in Late Mississippian-Early Pennsylvanian time is shown on figure 30. In south-central Kentucky, the cuesta bends around the Jessamine Dome on the Cincinnati Arch (see fig. 7) and extends northwestward into Indiana, dipping southwestward into the Eastern Interior basin. The best demonstration of the cuesta is Muldraughs Hill, a prominent escarpment capped by Upper Mississippian limestone that flanks the southwestern side of the Blue Grass region (see fig. 2).

The subcrop pattern of the Mississippian formations indicates southeast- to south-trending paleochannels are present across the subcrop. Those paleochannels are on the back slope of the cuesta which dips away from the Jessamine Dome, and they drain southeasterly in the northern part of the outcrop belt and more southerly in the southern part. What may be remnants of major paleochannels northwest of the cuesta that trend southwesterly are on Pilot Knob (fig. 4).

Extending northeastward from the vicinity of Pilot Knob, subaerial weathering has developed a paleokarst in the Newman Limestone.

LOWER BOUNDARY OF THE PENNSYLVANIAN SYSTEM

Although the Lee Formation in eastern Kentucky has generally been considerd to be the basal Pennsylvanian unit, stratigraphic studies in the last 20 years have placed the boundary between Mississippian and Pennsylvanian rocks in the Pennington or Lee Formations in parts of the Cumberland overthrust sheet, and in many other areas, at the base of the Breathitt Formation. Basal Pennsylvanian strata, but not the oldest Pennsylvanian strata, are best known from outcrops along the Pottsville Escarpment. There basal strata are commonly underclay, coal, or carbonaceous shale. Basal conglomerate and sandstone are rare and generally

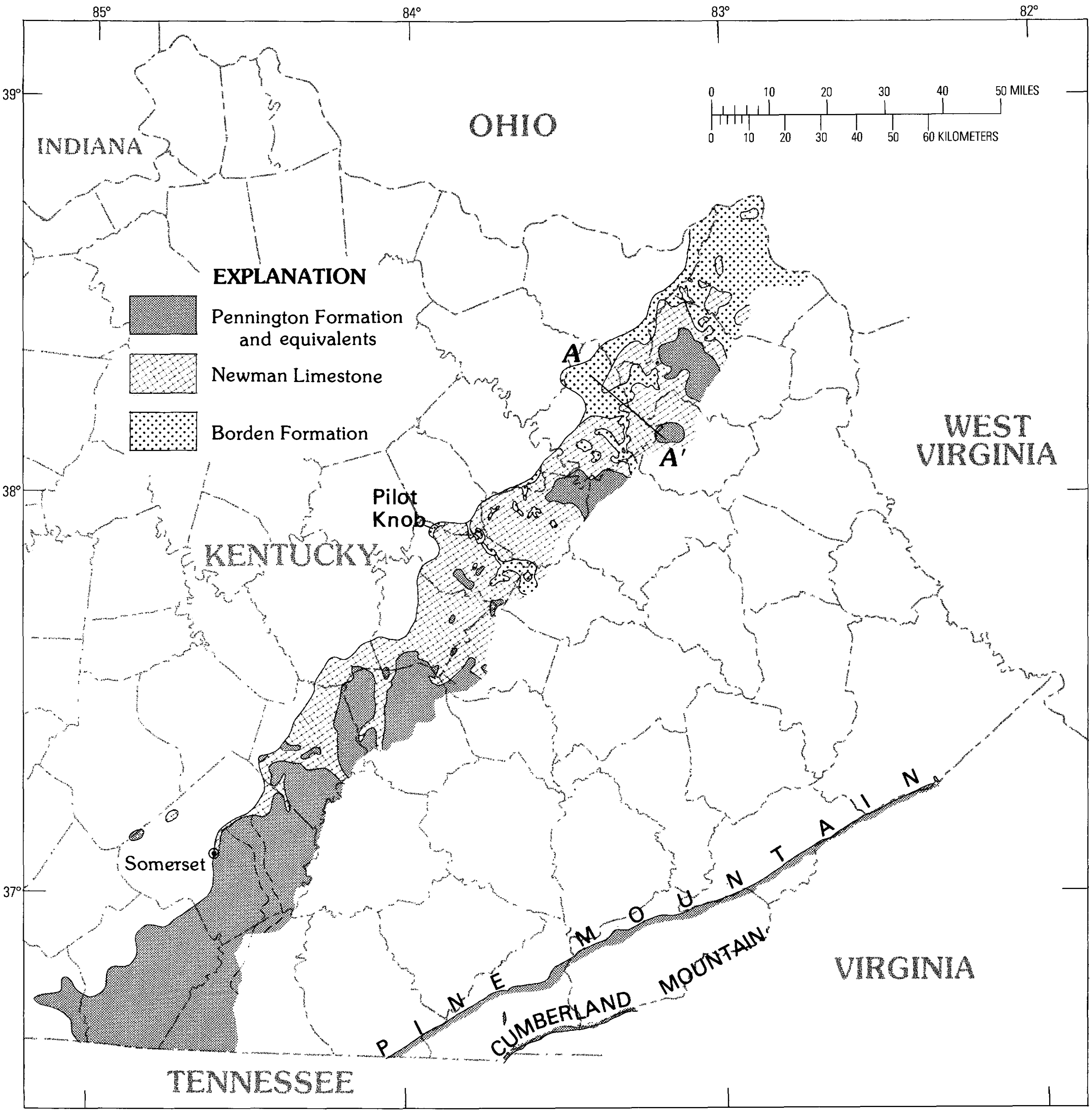


FIGURE 4.—Generalized geologic map of the sub-Pennsylvanian surface in areas of outcrop in eastern Kentucky.

occur only where paleochannels have been cut into the underlying Mississippian rocks. Generally the systemic contact separates terrestrial from marine rocks and is at the base of a thin coal bed that overlies limestone, red or green shale, or siltstone.

In most outcrops near the escarpment, the contact between Pennsylvanian and Mississippian rocks is a low-angle unconformity. Away from the sub-Pennsylvanian channels, the contact is locally a paraconformity which some workers have interpreted as a facies-related or transitional boundary (Haney, 1979). Thus in outcrops where Mississippian red and green shale are overlain by Pennsylvanian coal and bioturbated carbonaceous shale, the boundary may be misinterpreted as transitional. Where Upper Mississippian strata also contain thin coal beds, the nature of the systemic boundary can only be determined by local and regional lateral stratigraphic relations. Along the escarpment, the systemic boundary is commonly in poorly exposed sequences of shale and siltstone. However, on all detailed maps of the area, the boundary has been interpreted as an unconformity. The GQ Maps indicate that commonly at least 100 ft and locally more than 200 ft of underlying Mississippian strata were eroded prior to the deposition of strata of Pennsylvanian age.

In northeastern Kentucky, the existence of an unconformity that separated rocks of Mississippian and Pennsylvanian age was questioned by Horne and Ferm (1970), Horne and others (1971), Ferm and others (1971), Ferm (1974), and Horne and others (1974). They postulated a depositional model in which the largely terrestrial deposits above the unconformity are in facies relationship with marine strata below the unconformity. The "Lee-Newman barrier-shoreline model" of Horne and others (1971) identifies orthoquartzite (Lee Formation of Pennsylvanian age) as beach-barrier deposits that grade landward into lagoonal and lower delta-plain subgraywacke shale and coal (Breathitt Formation of Pennsylvanian age) and grade seaward into red and green shale (Pennington and Borden Formations of Mississippian age) that surrounded offshore carbonate islands (Newman Limestone of Mississippian age). This model does not consider the greatly different ages of the rocks as determined from the fossil evidence above and below the unconformity. Rather, the model postulates a westerly migrating shoreline environment of intertonguing terrestrial and marine sediments all of approximately the same age.

Field relations between rock units in northeastern Kentucky, the area for which the Lee-Newman barrier-shoreline depositional model was proposed, have shown the hypothesis to be untenable (Dever [1973] 1980; Rice and others, 1979, Ettensohn, 1979, p. 124). Distribution and thickness of marine and terrestrial rock units in this area are related to the movement of fault blocks during late stages of Mississippian and early stages of Pennsylvanian erosion and deposition (Sheppard, 1964). Furthermore, detailed mapping by Englund and Windolph (1971) has shown that the Carter Caves Sandstone mistakenly ascribed to the Lee Formation by Horne and others (1974, p. 102) underlies the unconformity and is Late Mississippian in age.

The unconformity between rocks of Mississippian and Pennsylvanian age is not as obvious toward the south and southeast. Englund and Smith (1960) reported that in the Cumberland Mountain area thick crossbedded, coarse-grained, quartzose conglomeratic sandstone of the Lee Formation grades laterally to thin, wavy-bedded, very fine-grained sandstone of the Pennington Formation. They interpreted the intertonguing and lat-

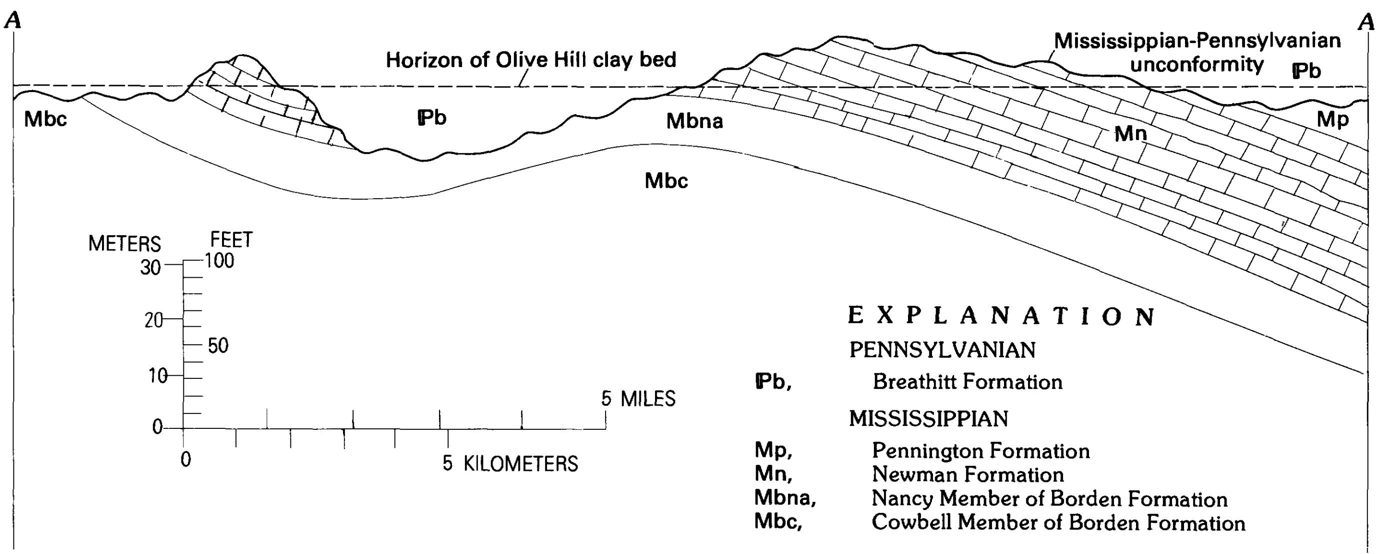


FIGURE 5.—Generalized section showing remnant northwest-facing cuestas of Mississippian limestone in northeastern Kentucky in Middle Pennsylvanian time. Datum is the Olive Hill clay bed of the Breathitt Formation of Middle Pennsylvanian age (Wanless, 1975a, p. 35). See figure 4 for location of section.

eral intergrading of the Lee and Pennington as evidence of partial contemporaneity of the formations and depositional continuity across the systemic boundary. As a result of the intertonguing and intergrading of the Pennington and Lee, poor exposures, and the lack of definitive paleontological data, the systemic boundary has not been precisely located in a large part of the Cumberland overthrust sheet. Geologic quadrangle reports along Cumberland Mountain published in the 60's and 70's show the systemic boundary to be at the base of either the Chadwell Member or the White Rocks Sandstone Member of the Lee. More recently, Englund (1979, p. C4; see also Miller, 1969, p. 9) stated that the White Rocks intertongues with the Bluestone Formation of Mississippian age (see fig. 8). Therefore, Englund placed the systemic boundary at the top of the White Rocks or at the base of the overlying Dark Ridge Member of the Lee Formation.

Authors of geologic quadrangle reports along much of Pine Mountain place the systemic boundary in the upper part of the Pennington Formation above the Little Stone Gap Member, which contains marine fossils of Mississippian age, and below coal beds and carbonaceous shales, which contain flora and microspores of Pennsylvanian age. Locally the systemic boundary is in the Middlesboro(?) Member of the Lee Formation in the outcrop belt of the central and southwestern parts of Pine Mountain because marine rocks of probable Mississippian age are reported in the lower part of the member.

In places in the Cumberland overthrust sheet, the base of the Pennsylvanian has been placed at the base of the Middlesboro Member of the Lee (or equivalent strata) where these rocks overlie marine strata of Mississippian age (Alvord and Miller, 1972; Miller, 1974; Englund, 1979). In these areas the systemic boundary is an unconformity, which Englund (1974, p. 238) suggests is probably coextensive with the widespread unconformity at the top of the Mississippian to the northwest.

In much of eastern Kentucky, basal Pennsylvanian strata, regardless of their age, are known only from scanty drill-hole data. Most logs of drill holes in eastern Kentucky lack detailed descriptions of lithologic units; the drillers commonly record only major changes in lithology that are useful for identifying formational units. Moreover, this part of the stratigraphic section generally lacks geophysical logs because Pennsylvanian strata and the upper part of the Upper Mississippian strata are not major targets in oil and gas exploration. Reasonable inferences, however, can be made from the drillers' logs about the nature of the Pennsylvanian strata and the position of the systemic boundary when these logs are interpreted with the aid of data from the study of nearest outcrops, drill cuttings and logs of the few coreholes, and the few geophysical logs of wells that penetrate this part of the section. Analyses of such data indicate that the systemic boundary is generally at the base of dark-gray carbonaceous shale and siltstone of Pennsylvanian age, which contrasts sharply with underlying calcareous red and green shale and siltstone of Mississippian age. The Mississippian strata locally contain dark-gray shale and sandstone in part similar to shale and sandstone in the Pennsylvanian but commonly differ from the Pennsylvanian as they are calcareous and interbedded with red and green shale and siltstone.

Three important lithostratigraphic reference surfaces relevant to the location of the systemic boundary are recognized in the subsurface. The first is the base of thick (greater than 100 ft) Pennsylvanian conglomerate, which may be at the boundary or as much as 200 ft above it. The second is the uppermost occurrence of red or green shale, which is characteristic of the Mississippian marine formations and is commonly immediately beneath the systemic boundary. The third reference surface, the top of the Newman Limestone, locally underlies Pennsylvanian shale and sandstone, as in much of northeastern Kentucky.

Figure 6 is a generalized contour map of the base of the Pennsylvanian System in eastern Kentucky. It is based largely on interpretations of data from drillers' logs and geologic quadrangle maps. The map shows the base of the Pennsylvanian System to be a surface generally inclined toward the southeast and locally broken by faults. Near the Pottsville Escarpment (see fig. 7), the contours reflect the mapped sub-Pennsylvanian erosion surface; elsewhere, most large features and irregularities are the result of post-Pennsylvanian folding. In easternmost Kentucky, however, the existence of a southwesterly trending paleovalley cut into the Mississippian surface is suggested by the −600 ft and −700 ft contours north of the trace of the Pine Mountain overthrust fault. The contours of this paleovalley and a suggested southeasterly trending distributary channel appear to coincide with thickness contours constructed by Miller (1974, p. 64) of the lowermost Pennsylvanian conglomeratic sandstone in Virginia and adjacent parts of Kentucky. The similarity of the structure contours and thickness contours indicates that the sandstone may be a channel fill. There is an elongate depression about 15 mi northwest of the paleovalley shown by the −400, −500, and −600 foot contours on figure 6 that may be a distributary channel from the paleovalley and which in turn apparently had distributaries of its own to the south and west.

Southeast of Pine Mountain, in the cross-faulted Cumberland overthrust sheet, the base of the Pennsylvanian is an asymmetrical trough with the deepest part on the southeast side. The shape of the trough east of

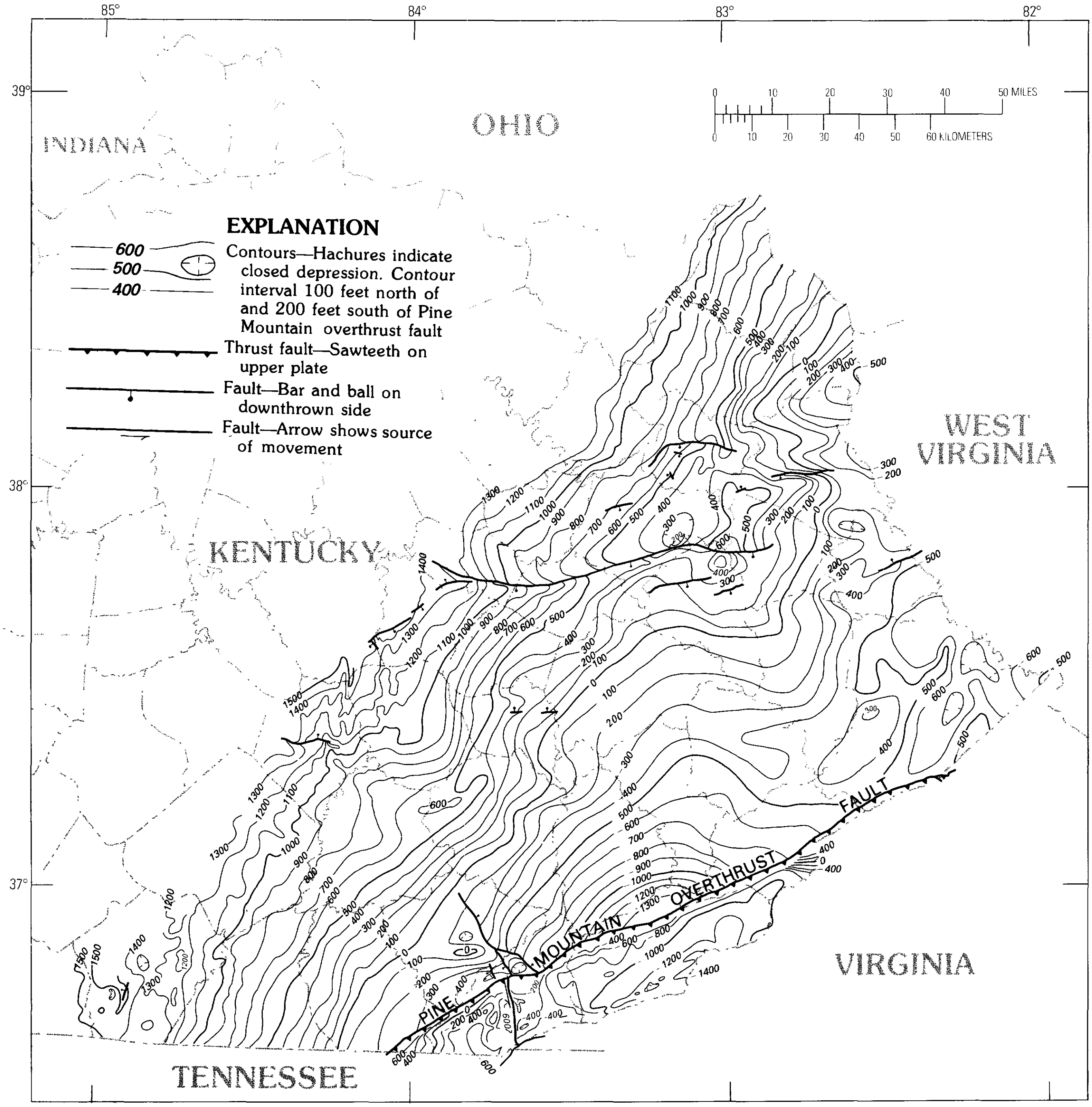


FIGURE 6.—Generalized contour map of the base of the Pennsylvanian System in eastern Kentucky, modified from Coskren and Rice (1979). Because of inaccuracies in recorded collar elevations and obscurities in drillers' logs, accuracy of detail in eastern Kentucky is probably about 100 ft north of the Pine Mountain overthrust fault and 200 ft south of the fault.

the Rocky Face fault may be due in large part to the location of the axis of a paleovalley near the southeastern side.

The flora of basal Pennsylvanian strata in Kentucky has been little studied. Assignment of relative ages to the basal strata in different parts of eastern Kentucky is therefore impossible except in the most general terms. The oldest Pennsylvanian strata of record in Eastern United States are east of Kentucky in southwestern Virginia and eastern West Virginia (Englund, Arndt, and Henry, 1979). Those strata are assigned to the Pocahontas Formation and contain a floral assemblage not found in Kentucky, though some species of the assemblage have been identified in the Dark Ridge member of the Lee Formation on Cumberland Mountain (Englund, 1979). Campbell, who named the Pocahontas Formation (Campbell, 1896) and the Lee Formation (Campbell, 1893) and who mapped extensively along the central and southern parts of the Pottsville Escarpment in Kentucky (Campbell, 1898a, b), pointed out that Early Pennsylvanian strata thinned toward the northwest across the Appalachian basin. He stated that much of the thinning was due to onlap and that as much as one-quarter of the basal Lee section is not present along the western border of the basin. Northeast of where Campbell mapped in northeastern Kentucky, extensive areas of basal Pennsylvanian strata of Middle Pennsylvanian age including the Olive Hill clay bed of the Breathitt Formation (Wanless, 1975a, p. 35) and the Corbin Sandstone Member of the Lee Formation rest on Mississippian rocks. Thus regional stratigraphic relations suggest that earliest Pennsylvanian deposition began in areas east of Kentucky and later Pennsylvanian deposition progressively onlapped an eroded Mississippian surface toward the northwest until Middle Pennsylvanian time when the Mississippian surface was completely buried in northeastern Kentucky.

GENERAL OUTLINE OF THE PENNSYLVANIAN SYSTEM IN EASTERN KENTUCKY

The Pennsylvanian rocks of eastern Kentucky lie in the central part of the Appalachian basin, a structural-depositional feature that extends from New York to Alabama. This coal-bearing sequence consists largely of sandstone, siltstone, and shale and forms a wedge that thickens southeastward toward the axis of the Appalachian basin. The axis of the basin lies parallel to but beyond the southeast border of Kentucky (see fig. 30).

The Pennsylvanian strata are about 1,500 ft thick in northeastern Kentucky where the section is most complete (in Kentucky) but relatively thin. Southeast of the Pine Mountain overthrust fault, the section is locally more than 4,600 ft thick, but in this area much of the upper part is missing due to erosion. A comparison of stratigraphic intervals in places in northeastern Kentucky with equivalent intervals in southeastern Kentucky shows a more than twenty-fold thickening southeastward.

Discontinuities and lateral and vertical variations of lithology in the Pennsylvanian strata, particularly those of Middle and Late Pennsylvanian age, make correlation and stratigraphic analysis difficult. Diagnostic marine and plant fossils are uncommon; few fossils have been intensively studied and most are assignable to wide-ranging forms.

In eastern Kentucky the Pennsylvanian includes the Lee, Breathitt, Conemaugh, and Monongahela Formations and part of the Pennington Formation locally at the base (fig. 7). The Lee crops out in two belts of steeply dipping strata southeast of the Pine Mountain overthrust fault on the Cumberland overthrust sheet. The Lee also crops out in a broad belt along the Pottsville Escarpment where the formation in part intertongues with and in part is overlain by the Breathitt Formation. The Conemaugh and Monongahela, undivided in Kentucky, crop out in a syncline in northeastern Kentucky where the stratigraphic section is generally thinnest.

The Pennsylvanian strata were deposited in deltaic, coastal plain, alluvial valley, swamp, marsh, and shallow lake and bay environments. Lower Pennsylvanian strata (parts of the Pennington, Lee, and Breathitt Formations), particularly in the southeastern part of the area, are dominated by thick, fining-upward sequences of conglomerate, pebbly sandstone, and sandstone units which are largely orthoquartzitic. Middle Pennsylvanian strata (parts of the Lee and Breathitt) generally consist of siltstone, shale, subgraywacke, and minor amounts of limestone, siderite, and many coal beds. The sandstone content of the preserved part of the Middle Pennsylvanian Series increases toward the east and generally upward in the section.

Figure 7 also shows the outcrop area of the Upper Pennsylvanian rocks in northeastern Kentucky. These deposits are assigned to the Conemaugh and Monongahela Formations and consist largely of grayish-red, greenish-gray, and variegated shale and siltstone which contrast with the gray hues of the underlying Lower and Middle Pennsylvanian rocks. Subgraywacke, in part pebbly, and minor amounts of limestone and calcareous shale are interbedded with the Upper Pennsylvanian shale and siltstone.

Dark-gray shale and thin lenses of limestone were deposited intermittently in eastern Kentucky in shallow marine and brackish environments during minor transgressions throughout the Pennsylvanian. The distribution of what appears to be the only Early Pennsylvanian marine transgression is illustrated in figure 35. The bulk of the marine rocks was deposited during Middle Pennsylvanian time. In general, evidence of the earlier transgressions is found in easternmost Kentucky and of the later transgressions in the middle and western parts of the outcrop area. During Late Pennsylvanian time, shallow seas made small incursions into northeastern Kentucky from the northwest (Rice and others, 1979, p. F19).

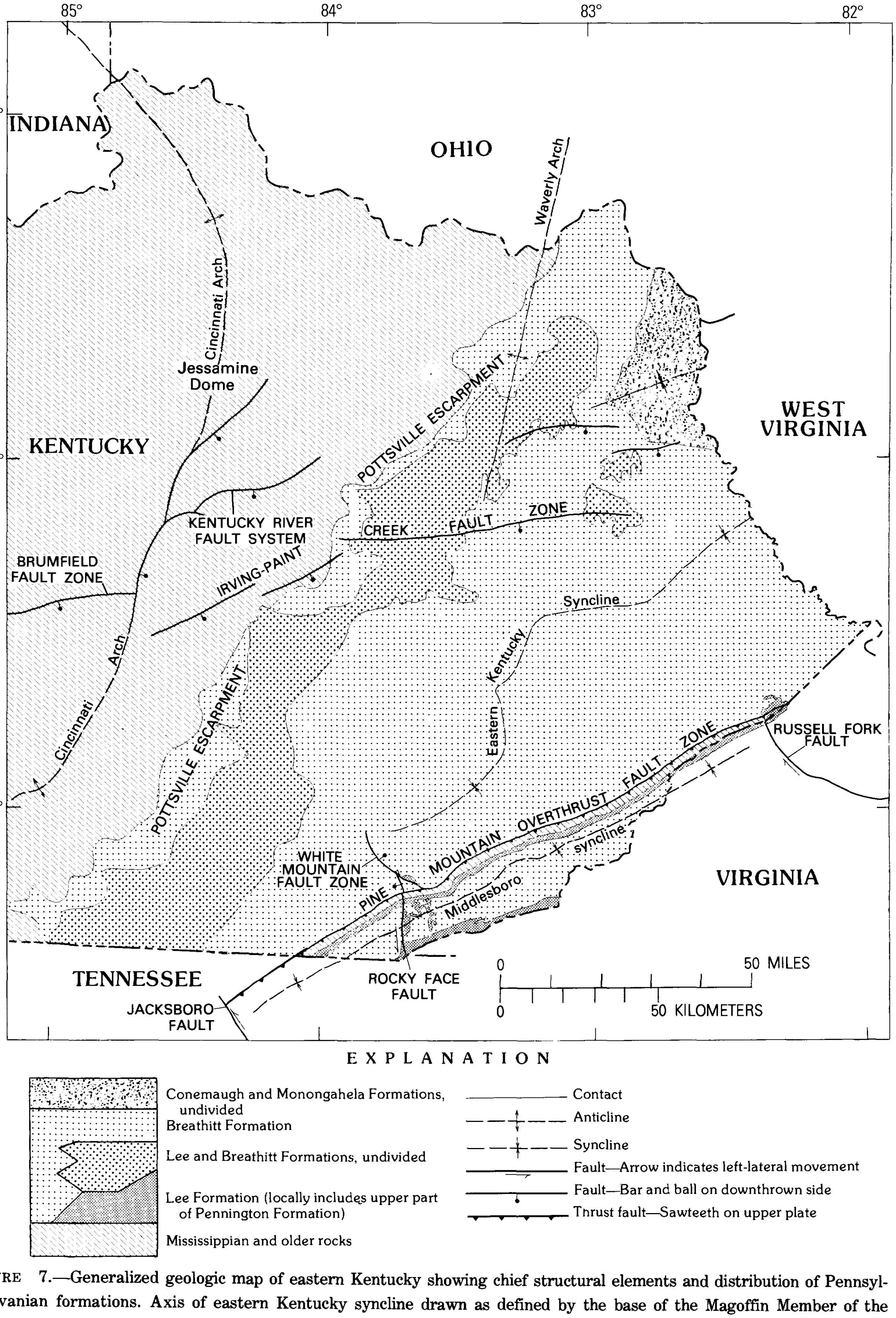


FIGURE 7.—Generalized geologic map of eastern Kentucky showing chief structural elements and distribution of Pennsylvanian formations. Axis of eastern Kentucky syncline drawn as defined by the base of the Magoffin Member of the Breathitt Formation.

The depositional pattern of Pennsylvanian strata was strongly influenced by subsidence along the axis of the Appalachian basin. This area of greatest subsidence may have periodically provided an avenue for invasion of marine waters into the easternmost part of the State as well as being a depocenter for fluvial distributary systems. The distribution of coarse clastics and marine rocks in the Pennsylvanian of eastern Kentucky suggests these strata were deposited by a southwestward and westward prograding delta system near sea level. Irregular subsidence resulted in the formation of local to large swamps now represented by coal beds and associated rocks.

THE PENNINGTON AND LEE FORMATIONS IN THE AREA OF THE CUMBERLAND OVERTHRUST SHEET

PENNINGTON FORMATION

The upper part of the Pennington as mapped along Pine Mountain locally includes carbonaceous shale and thin coal beds that contain Pennsylvanian flora (Maughan, 1976). This part of the Pennington is as much as 150 ft thick and is poorly exposed, mainly in the area of the Nolansburg and Roxana quadrangles (also see fig. 11). The relationship between mapped units suggests that channeling at the base of the Middlesboro Member of the Lee Formation has cut out Pennsylvanian strata of the Pennington along Pine Mountain northeast and southwest of the Bledsoe and Whitesburg quadrangles.

At its type section on Cumberland Mountain at Pennington Gap, Va., the Pennington is overlain by the White Rocks Sandstone Member of the Lee Formation. The uppermost shale unit of the type Pennington contains a thin coal bed of Late Mississippian age (Miller and Roen, 1973). Southwest along the Cumberland Mountain outcrop belt, the Pennington is also Mississippian in age and is overlain either by the White Rocks Sandstone Member or the older Chadwell Member of the Lee Formation. Northwest of the Pine Mountain fault, Pennsylvanian strata assignable to the Pennington were either eroded out or were not deposited, and the Mississippian Pennington strata are unconformably overlain by the Lee or Breathitt Formations.

LEE FORMATION

The Lee Formation of Late Mississippian and Early and Middle Pennsylvanian age was named by Campbell (1893) from exposures along the Cumberland Mountain outcrop belt in Lee County, Va. In the type area the formation is commonly more than 1,600 ft thick and consists largely of thick lenses of quartzose sandstone and conglomerate. The sandstone lenses are resistant and generally form prominent hogbacks at or near the crests of Cumberland and Pine Mountains and on Rocky Face Mountain, a large ridge just east of the Rocky Face fault (fig. 7). The Lee thins northwestward across the Cumberland overthrust sheet to Pine Mountain where the formation ranges in thickness from about 1,100 ft to 1,500 ft.

In the type area the Lee has been divided into eight members (fig. 8). The Pinnacle Overlook, Chadwell, White Rocks Sandstone, Middlesboro, Bee Rock Sandstone, and Naese Sandstone Members are mostly quartzose sandstone and conglomerate. The Dark Ridge and Hensley Members are mostly shale, siltstone, thin-bedded silty sandstone, and coal; but the Hensley also locally contains quartzose sandstone and conglomeratic sandstone.

PINNACLE OVERLOOK MEMBER

The Pinnacle Overlook Member (Mississippian) is named for a scenic overlook called the Pinnacle on the northeast side of Cumberland Gap on Cumberland Mountain (fig. 9).

> The lithology of the Pinnacle Overlook Member is typical of the Lee Formation and consists of thick-bedded, well-sorted, fine- to medium-grained quartzose sandstone in the lower and upper parts and massive conglomeratic quartzose sandstone in the middle part. Crossbedding is conspicuously developed throughout. The thickness increases from 230 feet at the Pinnacle Overlook to 360 feet approximately 2 miles northeast of Cumberland Gap. (Englund, 1964a, p. B33).

The lower and upper contacts of the Pinnacle Overlook Member and other similar sandstone tongues of the Lee and in the upper part of the Pennington Formation may be either gradational or sharp. Ripple bedding is conspicuous in the upper beds of the Pinnacle Overlook Member in the type area (fig. 10).

At the type area the Pinnacle Overlook Member overlies the marine Little Stone Gap Member of the Pennington Formation (Englund and DeLaney, 1966, p. D50). It is overlain by an unnamed marine unit of the Pennington that consists of greenish-gray and grayish-red shale locally containing a thin bed of fossiliferous limestone. Both fossiliferous marine units are discontinuous. Near the type area the Pinnacle Overlook Member is locally overlain by a quartzose sandstone, the Chadwell Member of the Lee Formation (Englund, 1964a).

The Pinnacle Overlook Member has been referred to informally as the "lower tongue of the Lee Formation" (Englund and others, 1964). On Pine Mountain pebbly quartzose sandstone bodies as much as 200 ft thick crop out in at least two stratigraphic levels in the Pennington Formation; the bodies at each level have been called a "sandstone tongue (?) of the Lee Formation"

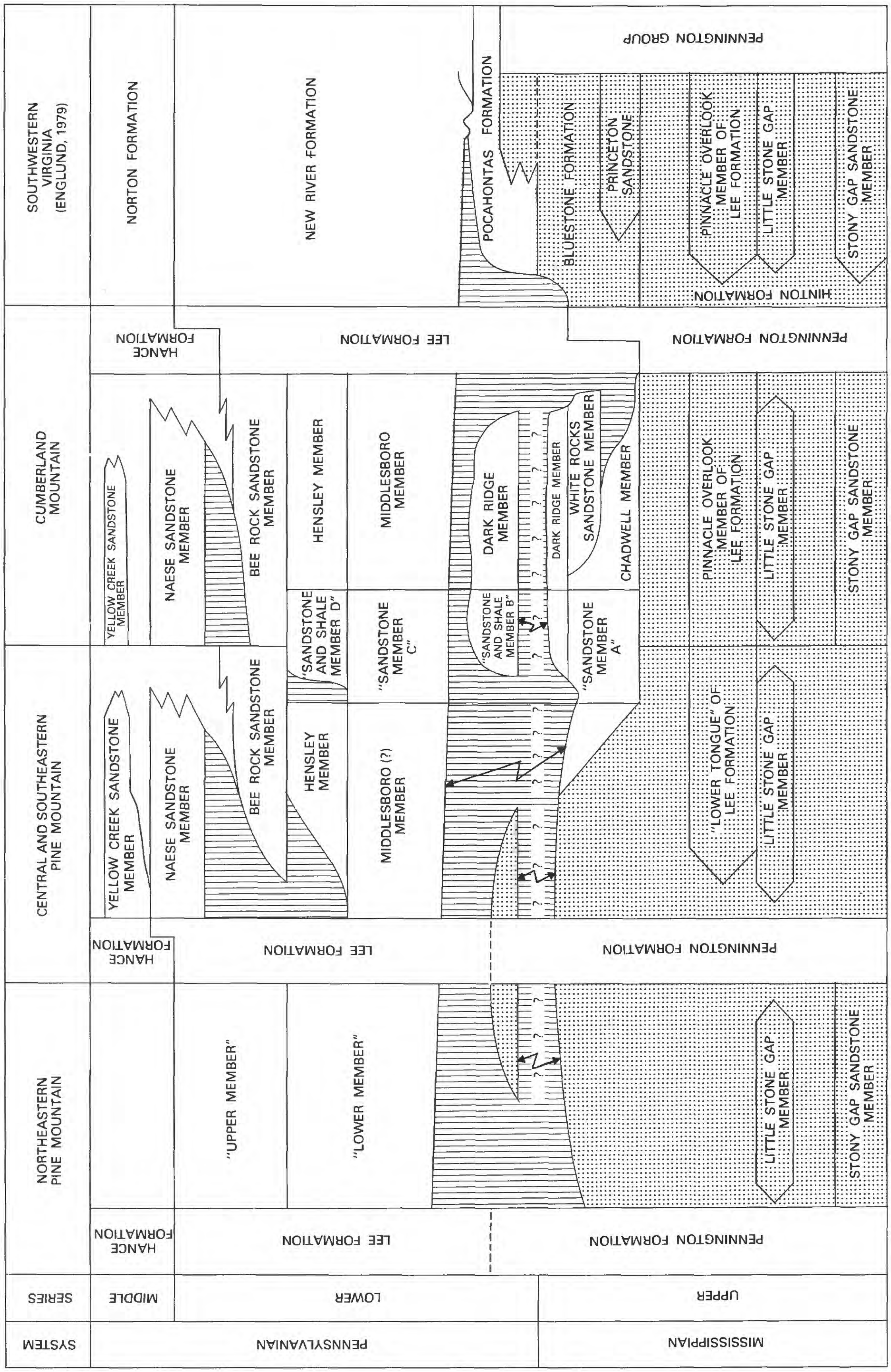


FIGURE 8.—Chart showing the correlation of the Pennington, Lee, and Hance Formations in the Cumberland overthrust sheet. Pennington strata shown by stippled pattern. Vertical lines indicate missing strata; queries show where the Mississippian-Pennsylvanian unconformity is projected in mapped units. Location of Pine and Cumberland Mountains are shown in figures 2 and 4.

FIGURE 9.—View of the Pinnacle Overlook Member of the Lee Formation near the Pinnacle on Cumberland Mountain.

(Csejtey, 1970; Froelich and Tazelaar, 1974). The lower and most persistent of these sandstone bodies along Pine Mountain is the "upper Maxton sand" of drillers (Wilpolt and Marden, 1959, plate 28, section D–D'). Wilpolt and Marden refer to the upper sandstone body, which is the Pinnacle Overlook Member, as the "Princeton Sandstone." In Tennessee, quartzose pebbly sandstone of Mississippian age is also reported in the Pennington (Milici and others, 1979) and has been mapped in places as the Pinnacle Overlook Member of the Lee Formation (Englund, 1968).

CHADWELL MEMBER

The Chadwell Member of the Lee Formation is named for exposures about 450 ft below the southeast side of Chadwell Gap on Cumberland Mountain about 10 mi northeast of Cumberland Gap (Englund, 1964a). The member consists of one or more resistant ledges of well-sorted, fine- to coarse-grained, quartzose sandstone which commonly has a thin basal bed containing quartz pebbles as much as 1 in. in diameter. The member locally grades into wavy-bedded, very fine-grained sandstone of the Pennington Formation. In places the member contains olive-gray shale as well as carbonaceous shale and thin coal beds. The member is about 180 ft thick at the type section. It thins to the northeast along Cumberland Mountain and thickens southwest of Cumberland Gap to as much as 350 ft where locally it is mostly conglomeratic sandstone. In places the Chadwell is directly overlain by the White Rocks Sandstone Member of the Lee Formation. Where directly overlain the two members commonly have been mapped as a single unit (Englund and others, 1964, p. B13). In localities, where the White Rocks wedges out, the Chadwell grades upward into the Dark Ridge Member of the Lee Formation.

The Chadwell Member has been referred to informally as "sandstone member A" and locally has been mapped as such near the Rocky Face fault on Pine Mountain in the Middlesboro North quadrangle (Englund and others, 1964). In adjacent areas on Pine Mountain, the Chadwell locally may be included in the lower part of Middlesboro (?) Member because neither the unconformity nor the members can be readily differentiated. The Chadwell is at the stratigraphic position of the Princeton Sandstone northeast of the type area in Virginia and West Virginia (Englund, 1979, p. C7) but apparently has no distinct correlatives to the southwest in Tennessee.

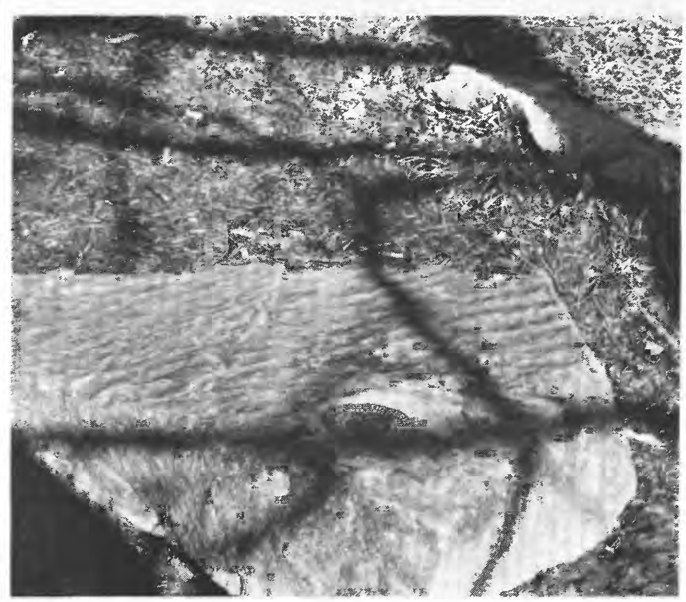


FIGURE 10.—Ripple bedding in the upper part of the Pinnacle Overlook Member.

WHITE ROCKS SANDSTONE MEMBER

The White Rocks Sandstone Member is named for a conspicuous south-facing cliff at the crest of Cumberland Mountain in the central part of the Ewing quadrangle (Englund and others, 1963). The sandstone is quartzose, fine to coarse grained, and has conglomeratic lenses containing well-rounded quartz pebbles ranging from 0.5 to 1 in. in diameter in troughs of large-scale festoon crossbeds (Tazelaar and Newell, 1974). The member includes an olive-gray, very fine-grained, wavy-bedded sandstone lens, 0 to 50 ft thick. The White Rocks Sandstone Member has a maximum thickness of 340 ft in its type area but pinches out both to the northeast and southwest along Cumberland Mountain. The member generally grades upward into the Dark Ridge Member. In the Hubbard Springs quadrangle, however, it is in places directly overlain unconformably by the Middlesboro Member of the Lee Formation (Tazelaar and Newell, 1974).

The White Rocks Sandstone Member has not been identified in the Lee Formation on Pine Mountain, but some beds correlative with it may be included in the lower part of the Middlesboro(?) Member, because the position of the unconformity has not been adequately located.

DARK RIDGE MEMBER

The Dark Ridge Member is named for exposures of thin-bedded sandstone and carbonaceous shale on the south end of Dark Ridge on the north side of Cumberland Gap in the Middlesboro South quadrangle (Englund, 1964a, p. B34). The member commonly contains several thin coal beds, including the Cumberland Gap coal bed which is as much as 4 ft thick in the type area. The member is about 60 ft thick at its type locality and is as much as 300 ft thick along the Cumberland Mountain where it is poorly exposed between massive sandstone units of the underlying Chadwell-White Rocks Sandstone and overlying Middlesboro Members. In the Ewing quadrangle, the upper part of the Dark Ridge includes a wavy-bedded, very fine-grained light gray and light-olive-gray sandstone that is locally as much as 120 ft thick (Englund and others, 1963, p. B15). The unconformity at the base of the overlying Middlesboro in places completely cuts out the Dark Ridge.

The Dark Ridge has been mapped and labeled "sandstone-and-shale member B" in the Middlesboro North quadrangle (Englund and others, 1964). Though it has not been identified on Pine Mountain, equivalent strata containing Pennsylvanian coal beds (Maughan, 1976) are probably included in the upper part of the Pennington Formation in the Nolansburg (Csejtey, 1970), Louellen (Froelich, 1973), Benham (Froelich and Stone, 1973), Roxana (Maughan, 1976) and Whitesburg quadrangles (Rice and Wolcott, 1973). Figure 11 shows that the Dark Ridge crops out in and underlies in a relatively narrow east-northeast trending area which lies just northwest of and along the axis of a sub-Pennsylvanian paleovalley (see also fig. 13). The relation of the Dark Ridge to the paleovalley suggests that it may consist in part of alluvial deposits of an Early Pennsylvanian river.

Englund and Delaney (1966, p. D49) have correlated the Dark Ridge Member with the Pocahontas Formation which contains a Lower Pennsylvanian flora including *Neuropteris pocahontas* in Russell County, Va. Although Englund (1979) has projected the Mississippian-Pennsylvanian boundary at the base of the Dark Ridge which, as noted previously, is gradational with either the underlying White Rocks Sandstone or Chadwell Members, it is possible that the systemic boundary may be a paraconformity within the Dark Ridge that has not yet been recognized. Descriptions of strata of the Dark Ridge commonly include wavy-bedded, very fine-grained, olive-gray sandstone that is more typical of Mississippian than Pennsylvanian rocks. But in the absence of definitive fossil data and good exposure, the position and character of the Mississippian-Pennsylvanian boundary within the Dark Ridge will remain unclear.

MIDDLESBORO MEMBER

The Middlesboro Member contains the thickest and most extensive sequences of conglomeratic sandstone beds that are assigned to the Lee Formation in the area of the Cumberland overthrust sheet. It forms prominent ridges along both Cumberland and Pine Mountains and makes up most of Rocky Face Mountain (fig. 12). The member was named for exposures just east of Middlesboro and north of Cumberland Gap in the Middlesboro South quadrangle (Englund, 1964a, p. B35).

The Middlesboro ranges from less than 300 ft to more than 700 ft in thickness (fig. 13). In its type area the member is about 475 ft thick, of which less than 30 ft is shale and siltstone. The sandstone is mostly thickly crossbedded, fine- to coarse-grained, and commonly contains quartz pebbles less than 1 in. but as much as 2.5 in. in diameter (fig. 14). The Middlesboro generally consists of three or four coalescing conglomeratic sandstone units that thin and pinch out to the east and southeast (Miller, 1974, p. 119) as well as to the northeast along Cumberland Mountain (Englund and Delaney, 1966). Thinning of the Middlesboro results from pinching out of individual sandstone units into sequences of shale, siltstone, and fine-grained subgraywacke that contain discontinuous coal beds. Massive quartzose conglomeratic sandstone units grade locally into thin-bedded, fine-grained subgraywacke (Englund and DeLaney, 1966). The Middlesboro contains coalified plant material and plant impressions, and in places thin beds of coal and carbonaceous shale (Miller, 1974, p. 61; Englund, 1968, p. 17). The basal contact of the member is an unconformity that has a local relief of only a few feet (fig. 15). The regional relief at the contact may be as much as 400 ft, because the unconformity in some areas truncates the Dark Ridge Member and cuts into either the Chadwell or White Rocks Sandstone Members. The upper contact of the Middlesboro is locally sharp but commonly is gradational into or intertonguing with the overlying unit.

The Middlesboro Member is map unit "sandstone member C" on some quadrangles covering parts of Pine and Cumberland Mountains (Englund and others, 1964). Along much of Pine Mountain, the Middlesboro is queried because it may contain unrecognized members of the Pennington and Lee Formations. For example, in the Wallins Creek quadrangle, the basal conglomeratic sandstone bed of the Middlesboro(?) Member is in places overlain by a unit, as much as 60 ft thick, composed of brachiopod-bearing, olive-gray, slightly calcareous shale (Froelich, 1972). This fossiliferous unit may be Mississippian in age and is perhaps separated by an unrecognized unconformity from overlying sandstone correlative with the type Middlesboro. Marine fossils have not been found elsewhere in the Middlesboro or Middlesboro(?) Member in Kentucky.

The Middlesboro Member was not mapped at the northeast end of Pine Mountain, but it is probably equivalent to both the lower and middle sandstone members of the Lee Formation of Alvord (1971) and all of the lower member and most of the upper member of the Lee Formation of Rice (1973). To the southwest, the Middlesboro is mapped in Tennessee in areas adjacent to Kentucky (Englund, 1968). In the nomenclature of the Tennessee Division of Geology, the Middlesboro Member may be equivalent in part to the Warren Point Sandstone of the Gizzard Group and is probably equivalent to the Sewanee Conglomerate and Newton Sandstone of the Crab Orchard Mountains Group (Milici and others, 1979, p. 63).

Figure 13 shows the general variations in thickness of the Middlesboro, the thickest member of the Lee Formation. East of Rocky Face fault, the member is thickest along the axis of a southwest-trending linear

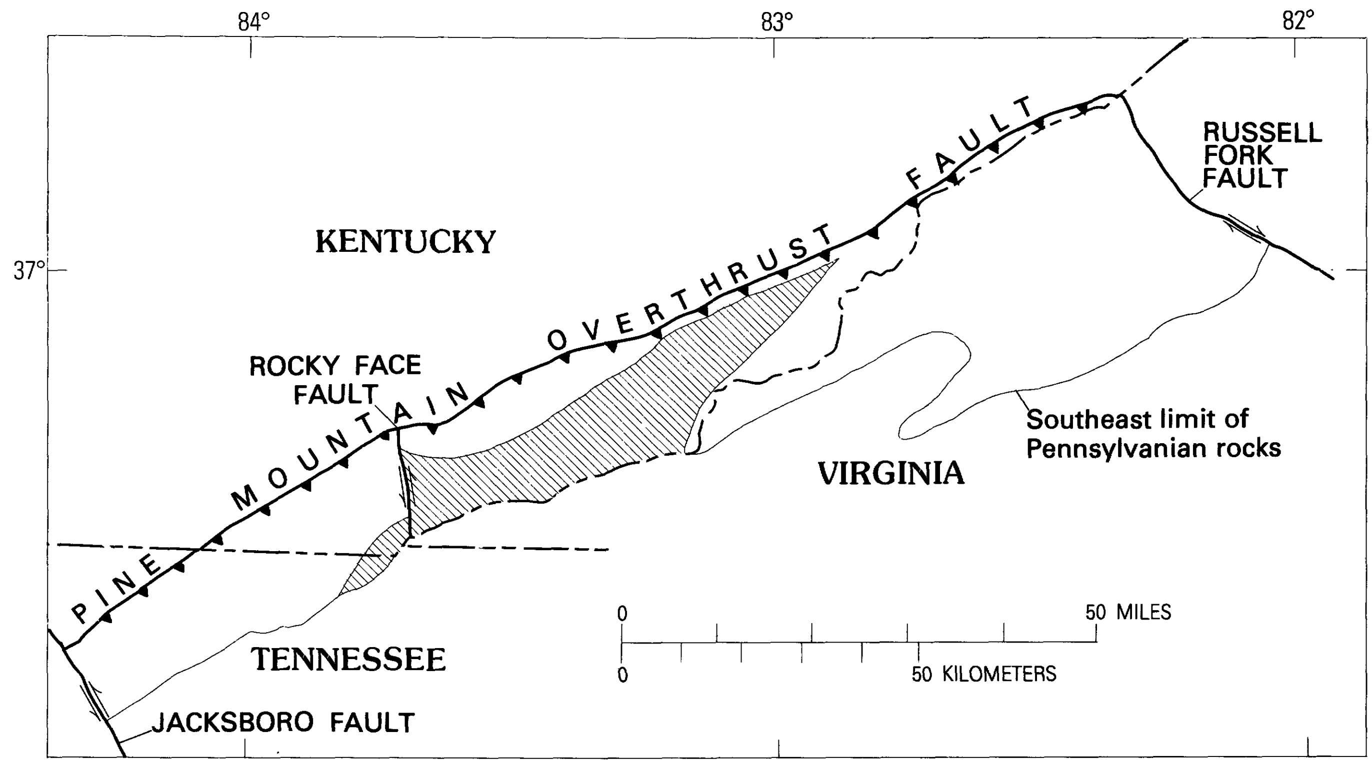


FIGURE 11.—Distribution of the Dark Ridge Member of the Lee Formation and correlative strata of the Pennington Formation of Pennsylvanian age (patterned).

FIGURE 12.—View of dipping strata of the Middlesboro Member of the Lee Formation on Pine Mountain just south of Pineville, Ky. View is toward the east across the Rocky Face fault where the Cumberland River cuts through Pine Mountain. Sandstone cliffs in the background to the right side of the photo are part of the Bee Rock Sandstone Member of the Lee Formation.

feature that is a continuation of a similar feature on figure 6 previously identified as a paleovalley. The continuity of the paleovalley across the Pine Mountain overthrust fault is more obvious if the Cumberland overthrust sheet on figure 13 is moved about 4 mi to the southeast to its original position estimated by Englund (1974, p. 33) for the area near the Russell Fork fault.

A second paleovalley, on the west side of and roughly alined with the Rocky Face fault, is suggested by the great variations in thickness of the Pennington Formation and of the Middlesboro Member from the east to the west side of the Rocky Face fault on Pine Mountain. The Pennington thins from about 1,100 to 400 ft; the Middlesboro thickens from about 300 to 500 ft. Paleocurrent directions for the fluvial sandstones in the Lee Formation in the Cumberland overthrust sheet are generally southwesterly; however, they show a southerly trend near the Rocky Face fault, perhaps reflecting the influence of south-trending channels in this valley (BeMent, 1976).

A third paleovalley is indicated at the southwestern end of the Cumberland overthrust sheet where strata of the Middlesboro attain a thickness in excess of 600 ft.

HENSLEY MEMBER

The Hensley Member, named for exposures in Hensley Flats (Englund, 1964a, p. B36), comprises the largely nonresistant beds that lie between the top of the ridge-forming Middlesboro Member and the base of the overlying cliff-making Bee Rock or Naese Sandstone Members of the Lee Formation. The Hensley consists mostly of shale, siltstone, and thin-bedded subgraywacke but locally contains resistant beds of quartzose sandstone and conglomeratic sandstone; one such conglomeratic sandstone has been mapped from the Balkan quadrangle (Froelich and Tazelaar, 1973) northeastward along Pine Mountain to

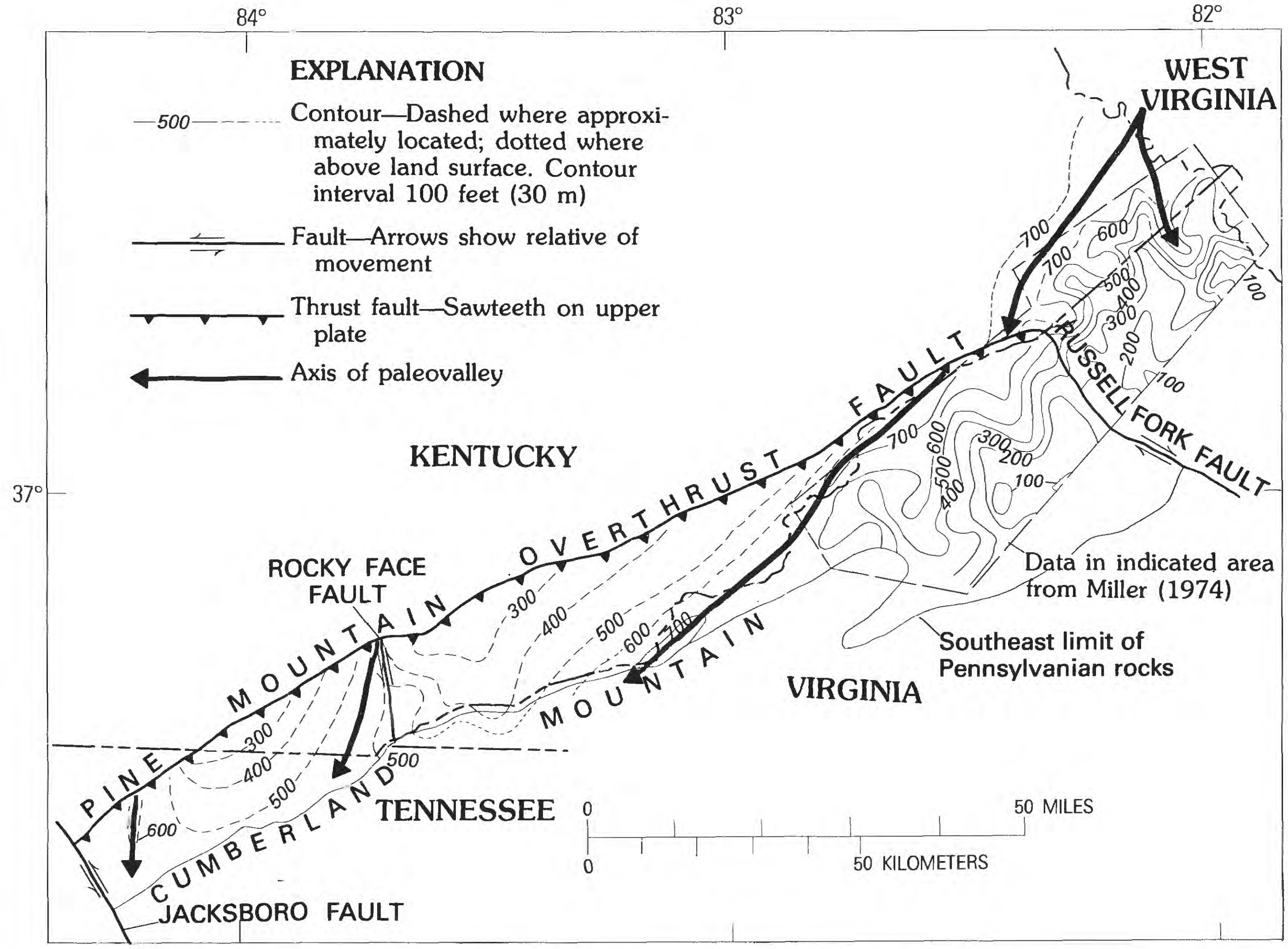


FIGURE 13.—Generalized thickness contours of the Middlesboro Member of the Lee Formation in the Cumberland overthrust sheet. Contours are based on interpretation of published data in geologic quadrangle maps. About two-thirds of the Middlesboro(?) Member on Pine Mountain is here considered to be equivalent to the type Middlesboro. Subsurface contours in Virginia and adjacent parts of Kentucky are based on isolith maps of Miller's (1974, figs. 43, 44) lower and middle quartz arenite members of the Lee, which are approximately equivalent to the Middlesboro.

the Bledsoe quadrangle (Csejtey, 1971). Thin coal beds and underclays are common in the member. The widespread Tunnel coal bed, which ranges from 0 to 50 in. in thickness, occurs at or near the top of the Hensley. At the type section, along Skyland Road and U.S. Highway 25 E on the northwest side of Cumberland Gap, the Hensley is about 350 ft thick. Along Cumberland Mountain and Pine Mountain east of Rocky Face fault, the member ranges in thickness from about 200 to 450 ft. West of Rocky Face fault on Pine Mountain, the Hensley is generally less than 200 ft thick and is truncated by the unconformity at the base of the overlying Bee Rock or Naese Sandstone Members (Englund and others, 1964).

The Hensley was locally called "sandstone and shale member D" (Englund and others, 1964) (fig. 6). In the northeastern part of Pine Mountain, the Hensley is the unnamed map unit composed of shale, siltstone, and sandstone that lies between the middle and upper sandstone members of the Lee Formation of Alvord (1971). In some quadrangles, it has been included in the upper part of the middle member of the Lee Formation

(Rice, 1973). To the southwest, the Hensley is mapped in some areas in Tennessee adjacent to Kentucky (Englund, 1968). The Hensley is probably equivalent in the nomenclature of the Tennessee Division of Geology to the sequence of shale, siltstone, and sandstone that overlies the Sewanee Conglomerate or Newton Sandstone and underlies the Rockcastle Conglomerate.

BEE ROCK SANDSTONE AND NAESE SANDSTONE MEMBERS

The uppermost members of the Lee Formation are the Bee Rock Sandstone and Naese Sandstone. The Bee Rock is the topmost member in most areas east of Rocky Face fault and the Naese is the topmost member west of the fault (fig. 16). In most areas where the Naese is present, it unconformably overlies the Bee Rock. In places the Naese apparently entirely replaces the Bee Rock (Englund and others, 1964).

FIGURE 14.—Basal conglomeratic beds of the Middlesboro member of the Lee Formation near Hanging Rock on U.S. Highway 421 near Harlan, Ky.

FIGURE 15.—View of Hanging Rock on U.S. highway 421 near Harlan, Ky., showing the unconformity at the base of the Middlesboro Member of the Lee Formation where it overlies thin-bedded sandstone and siltstone of the Pennington Formation.

The Bee Rock Sandstone Member was named from exposures at Big Stone Gap, Va., about 6 mi east of Kentucky on Cumberland Mountain (Campbell, 1893). As shown in figure 16, the member pinches out to the southeast in western Virginia. In Kentucky the Bee Rock ranges from about 80 to 325 ft in thickness and generally thickens toward the northwest. The basal contact of the Bee Rock, though a disconformity with a local relief of several tens of feet, is a useful stratigraphic datum in the Lee Formation east of Rocky Face fault where it overlies the nonresistant Hensley Member. West of Rocky Face fault, the lower boundary of the Bee Rock is locally difficult to identify in those places where the underlying Hensley is thin and poorly exposed. In the localities where the Bee Rock is not overlain by the Naese, it grades into and locally intertongues with the overlying Hance formation. At the northeast end of Pine Mountain, the Bee Rock is partly or wholly equivalent to the upper member of the Lee Formation (fig. 8) or to the upper sandstone member of Alvord and Miller (1972).

The Naese Sandstone Member was named for Naese Cliff, a conspicuous topographic feature on Cumberland River about 8 mi east-southeast of Pineville, Ky. (Ashley and Glenn, 1906, p. 35). The cliff is situated near the eastern limit of the member (fig. 16) where the member grades laterally to shale and very fine to fine-grained, thin-bedded sandstone of the Hance Formation (Englund and others, 1963). The Naese decreases in grain size upward and grades laterally into strata of the overlying Hance; where the overlying Yellow Creek Sandstone Member of the Hance directly overlies the Naese, the two are locally mapped as a single unit (Englund and others, 1964). In the type area, the Naese is as much as 250 ft thick.

The sandstone of both the Bee Rock Sandstone and Naese Sandstone Members is quartzose, fine- to coarse-grained, pebbly to conglomeratic, and has quartz pebbles as much as 0.5 in. in diameter. Where the Naese rests on the Bee Rock, identification of the boundary between the members is difficult because of their

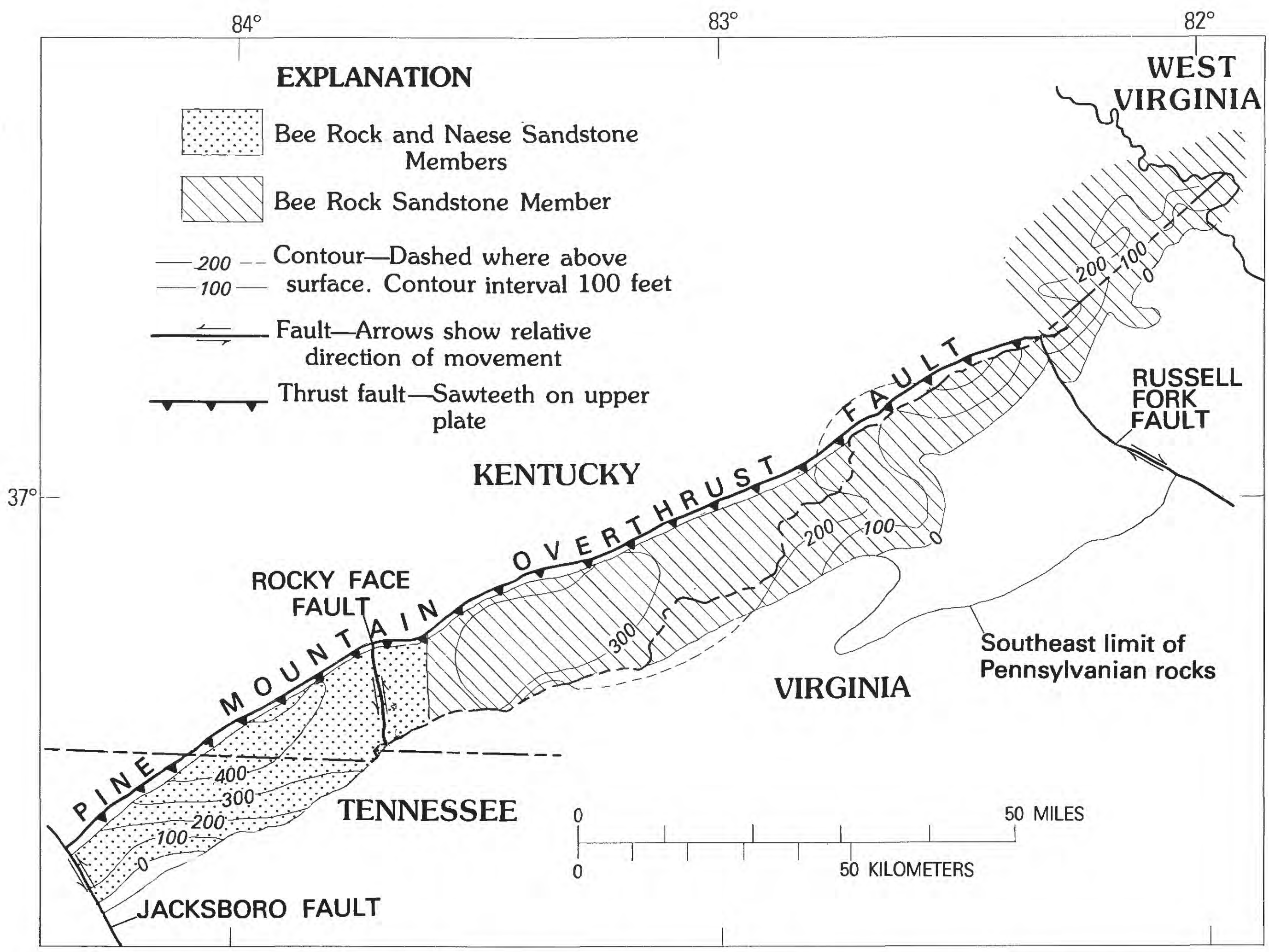


FIGURE 16.—Map showing thickness contours for the Bee Rock Sandstone Member of the Lee Formation east of Rocky Face fault and those for the combined Bee Rock Sandstone and Naese Sandstone Members of the Lee Formation west of Rocky Face fault in the Cumberland overthrust sheet and nearby areas in Virginia and Kentucky. Contours for the Bee Rock in the subsurface in the northeastern part of the area are generalized from Miller (1974, p. 69, fig. 45).

lithologic similarity. This difficulty has resulted in different interpretations of the distribution of these members. Englund (1968, p. 18) suggests that the Bee Rock is truncated by an unconformity at the base of the Naese west of Cumberland Gap and is absent in Tennessee; he (1968, plate 4) also shows the Naese wedging out southeastward in Tennessee. In this report, the Bee Rock and Naese are treated as a single unit in areas west of the Rocky Face fault. Geological quadrangle reports suggest that these combined units thicken northwestward in Kentucky from a minimum of about 200 ft on Cumberland Mountain to as much as 400 ft on Pine Mountain.

Lee sandstone and conglomerate beds crop out locally north of Pine Mountain along the White Mountain fault zone in the Pineville quadrangle (Froelich and Tazelaar, 1974); these strata are probably equivalent to the combined Bee Rock and Naese Sandstone Members (see figs. 7 and 17). Lee sandstone and conglomerate beds are also preserved locally in fault slices in the Pine Mountain overthrust fault zone.(See figure 17.)

The Bee Rock and Naese are partly or wholly equivalent to the Rockcastle Sandstone Member of the Lee Formation where it crops out along the Pottsville Escarpment on the northwestern border of the Appalachian basin in eastern Kentucky (Englund, 1968, p. 18). These members are also probably equivalent to the Rockcastle Conglomerate of the Crab Orchard Mountains Group in the nomenclature of the Tennessee Division of Geology (Milici and others, 1979, p. G3).

The top of the Lee Formation in the Cumberland overthrust sheet has traditionally marked the boundary between the Lower and Middle Pennsylvanian Series in southeastern Kentucky. Recently Englund and others (1979, p. 72–73) have placed the series boundary in the proposed Pennsylvanian System stratotype section in West Virginia at a stratigraphic level above equivalents to the Bee Rock Sandstone Member. The Naese Sandstone Member, because it overlies the Lower Pennsylvanian Bee Rock, may range in age from Early to Middle Pennsylvanian.

LEE AND BREATHITT FORMATIONS ALONG THE NORTHWESTERN PART OF THE EASTERN KENTUCKY COAL FIELD

By C. L. Rice and G. W. Weir

The Lee Formation along the western margin of the eastern Kentucky coal field is characterized, like the Lee of the type area, by massive cliff-forming sequences of quartzose, in part conglomeratic, sandstone. The sandstone cliffs form the Pottsville Escarpment. The name Lee was first applied along the Pottsville Escarpment by Campbell (1898a, b) who placed the top of the formation at the top of the Corbin Sandstone Member and assigned all underlying Pennsylvanian strata to the Lee Formation. Campbell (1898b, p. 3) assigned the overlying Pennsylvanian strata, which consist largely of shale, siltstone, and subgraywacke, to the Breathitt Formation. The name was taken from Breathitt County, Ky., which lies more than 20 mi east of the area that he mapped. Campbell's selection of the top of the Corbin for a formation boundary is unsatisfactory, because the member does not extend through the area. Along its margins, the Corbin pinches out into shale and siltstone or grades into nonresistant subgraywacke indistinguishable from sandstone in the Breathitt.

Geologists in the early part of the quadrangle-mapping program attempted to adapt Campbell's nomenclature to the different stratigraphic conditions of their map areas. Some placed the contact between the Lee and Breathitt at the top of the Corbin. Other geologists placed the contact at the top of the highest resistant quartzose sandstone or at the base of an overlying coal bed. On a few maps, the Lee-Breathitt boundary was projected without a contact being shown. Where no mappable criteria were available, the strata were designated as "Lee and Breathitt Formations, undivided."

Detailed geologic mapping along the western margin of the coal field gradually made clear that the Lee intertongued and graded laterally into the Breathitt. The application of the name "Lee Formation" was restricted in the area to those previously named sandstone members of the Lee that were shown by mapping to have regional extent (Weir and Mumma, 1973). Only three members, whose distribution is shown in figure 17, meet these criteria: the Livingston Conglomerate Member, the Rockcastle Conglomerate Member, and the Corbin Sandstone Member. The general relation of these Lee members to those described in the Cumberland overthrust sheet is shown in figure 18. Another stratigraphic unit, the Grayson sandstone bed of Whittington and Ferm (1967) of the Lee Formation, is commonly thin and has been mapped locally in a few quadrangles in northeastern Kentucky.

Several formal and informal members of the Lee have been used in the geologic-quadrangle reports. These include the Beattyville Shale Member, the Marsh Creek Sandstone Tongue, the Upper Corbin Sandstone Tongue, and several sandstone and shale members designated by alphabetic letters. The Beattyville Shale Member, because it was poorly defined and had been applied to different stratigraphic intervals, has been abandoned (Weir, 1975). The Marsh Creek Sandstone Tongue, whose type section is in the northwestern part of the Hollyhill quadrangle, is described as the "first cliff-forming, thick-bedded sandstone stratigraphically below" the Corbin Sandstone Member (Loney, 1967).

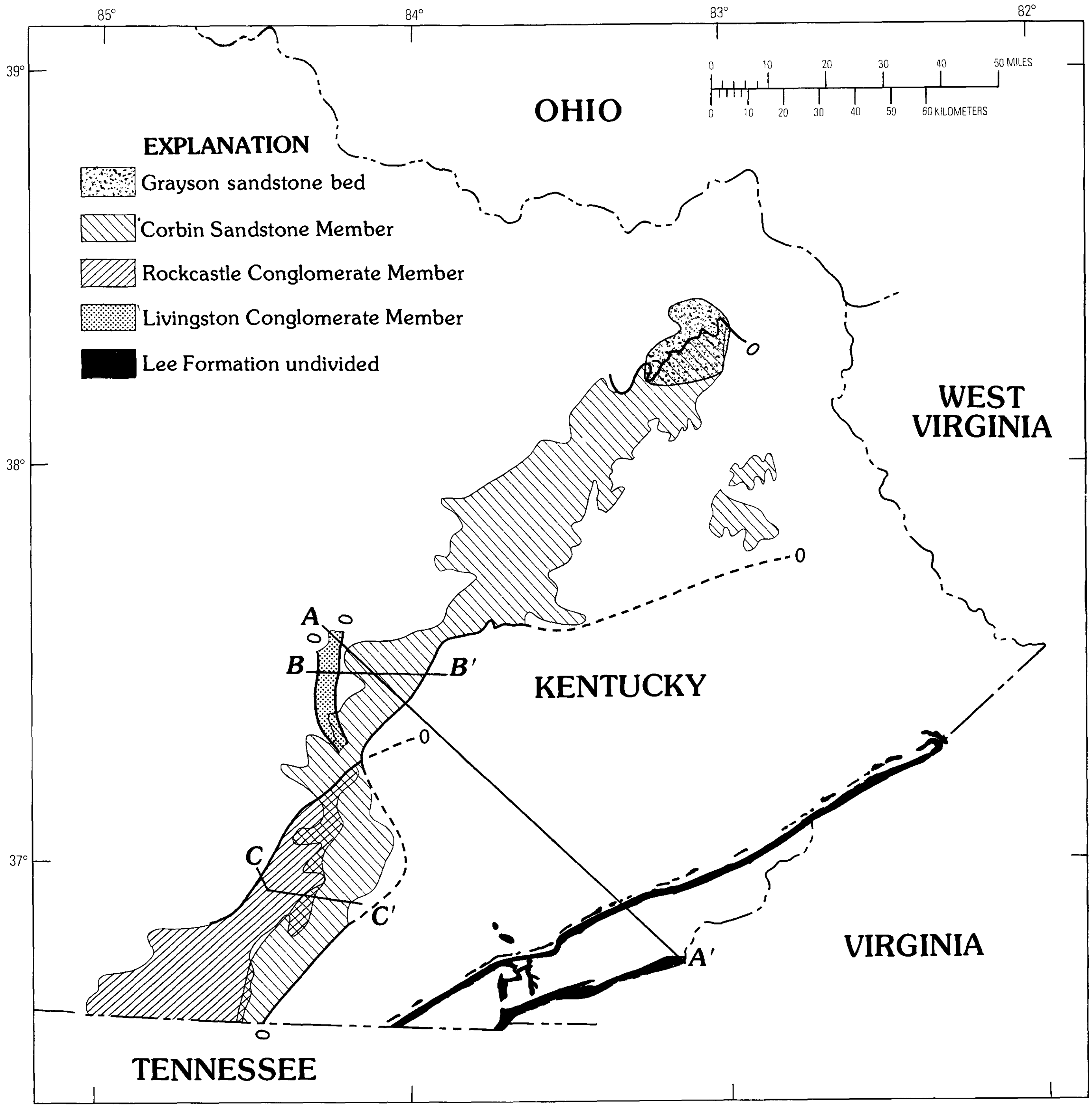


FIGURE 17.—Generalized outcrop map of the Lee Formation in eastern Kentucky showing the distribution of members in the western part of the area. The depositional pinchouts of members are shown by zero isopachs. Cross section A - A′ is shown in figure 18. Cross sections B - B′ and C - C′ are shown in figure 25.

The Marsh Creek has not been extensively mapped, and its relation to the Corbin in adjacent areas is not clear. The name "Upper Corbin Sandstone Tongue" was applied in the Hollyhill quadrangle to a sandstone unit that overlies the River Gem coal bed (Loney, 1967). The sandstone unit is now known to be younger than the Corbin Sandstone Member. Its lithologic characteristics as well as its stratigraphic position suggest that the sandstone unit is a part of the Breathitt Formation (Rice and Newell, 1975).

LIVINGSTON CONGLOMERATE MEMBER OF THE LEE FORMATION AND RELATED SANDSTONE UNITS

The Livingston Conglomerate Member was named by Miller (1908, p. 28) for exposures of conglomeratic sandstone near Livingston, Ky (fig. 19). It consists of interstratified and intergraded sandstone and conglomerate in deposits as much as 120 ft thick that occupy a paleovalley as much as 4 mi wide and more than 20 mi long (fig. 20A). The sandstone is composed of subangular to subrounded, fine to coarse grains of clear quartz, and sparse to abundant well-rounded quartz and minor chert pebbles mostly less than 1 in. in diameter (fig. 21). The Livingston contains some blocks of limestone near its base and sparse chert fragments and pebbles derived from the underlying Mississippian carbonates. Crossbeds of the member indicate a southerly current direction (fig. 20B).

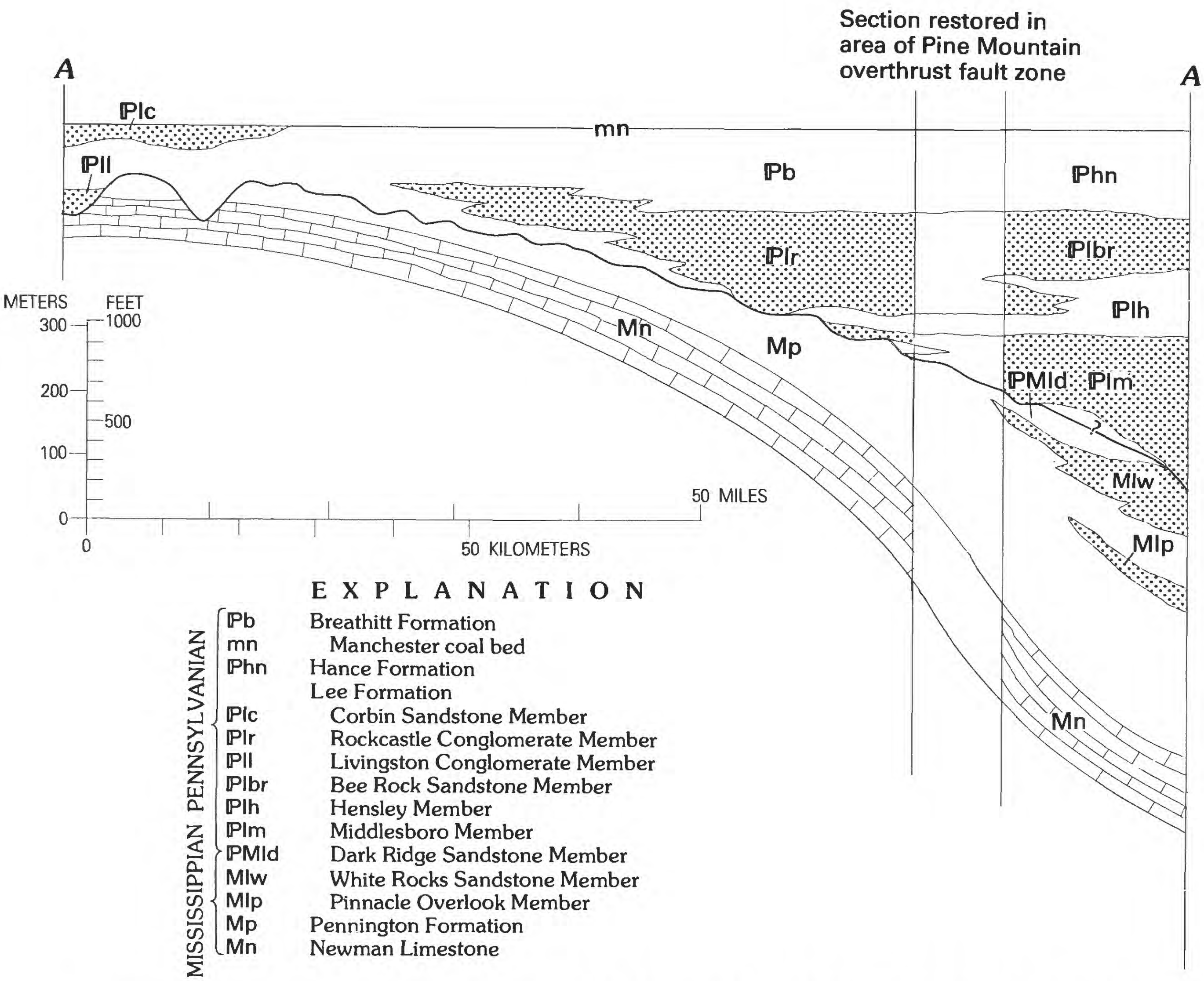


FIGURE 18.—Schematic cross section showing relations of major members of the Lee Formation in eastern Kentucky. Datum is top of Corbin Sandstone Member of the Lee Formation or base of overlying Manchester coal bed of the Breathitt Formation. Heavy line is Mississippian-Pennsylvanian unconformity that is locally projected within the Dark Ridge member of the Lee and equivalent strata.

FIGURE 19.—Outlier of the Pottsville Escarpment, Indian Fort Mountain near Berea, Ky., near the northern limits of outcrop of the Livingston Conglomerate Member of the Lee Formation. The Livingston, the darker cliff-forming unit capping the ridge, rests on strata of the Newman Limestone, the lighter cliff-forming unit.

The Livingston paleovalley (fig. 20A) is the largest of four conglomerate- and sandstone-filled paleovalleys that cross the sub-Pennsylvanian outcrop belt. The distribution of conglomerate and sandstone deposits in a paleovalley in the western part of Alcorn quadrangle about 6 mi east of the Livingston channel (fig. 22) suggests that the valleys and their fill were the results of several episodes of erosion and deposition (Rice, 1972). A paleovalley several miles east of Pilot Knob (fig. 4) cuts Mississippian strata as old as the Cowbell Member of the Borden Formation (Weir and Richards, 1974). The channel fill is mostly fine- to medium-grained pebbly sandstone but also contains pebbles and cobbles as much as 10 in. in diameter of chert derived from the Newman Limestone. These three paleovalleys had small tributaries now represented by poorly exposed, discontinuous lenses of pebbly sandstone on ridgetops.

A major paleovalley east of Somerset, Ky. (fig. 4), cuts through the Pennington Formation at the northern end of the paleovalley. Details of the geology of this paleovalley are not well known, because the Pennington is poorly exposed and the Pennsylvanian fill consists of nonresistant siltstone and shale as well as discontinuous lenses of sandstone and pebbly sandstone.

Another paleovalley is represented by isolated channel deposits along the Pottsville Escarpment in the Levee quadrangle (McDowell, 1978) at Pilot Knob. These deposits, identified as Lee Formation by McDowell (1978), are from 150 to 200 ft stratigraphically below the southeast- or south-trending channels that cross the sub-Pennsylvanian outcrop belt. They are thought to be remnants of a southwest-trending drainage system that extended from Ohio across central Kentucky into the Eastern Interior basin in western Kentucky. The conglomerate and conglomeratic sandstone that fills the channel on Pilot Knob (see fig. 4) in the Levee quadrangle is as much as 125 ft thick and contains rounded to well-rounded pebbles as much as 1.5 in. in diameter (figs. 23 and 24). Crossbedding in these rocks indicates a dominant southwesterly or southerly current direction.

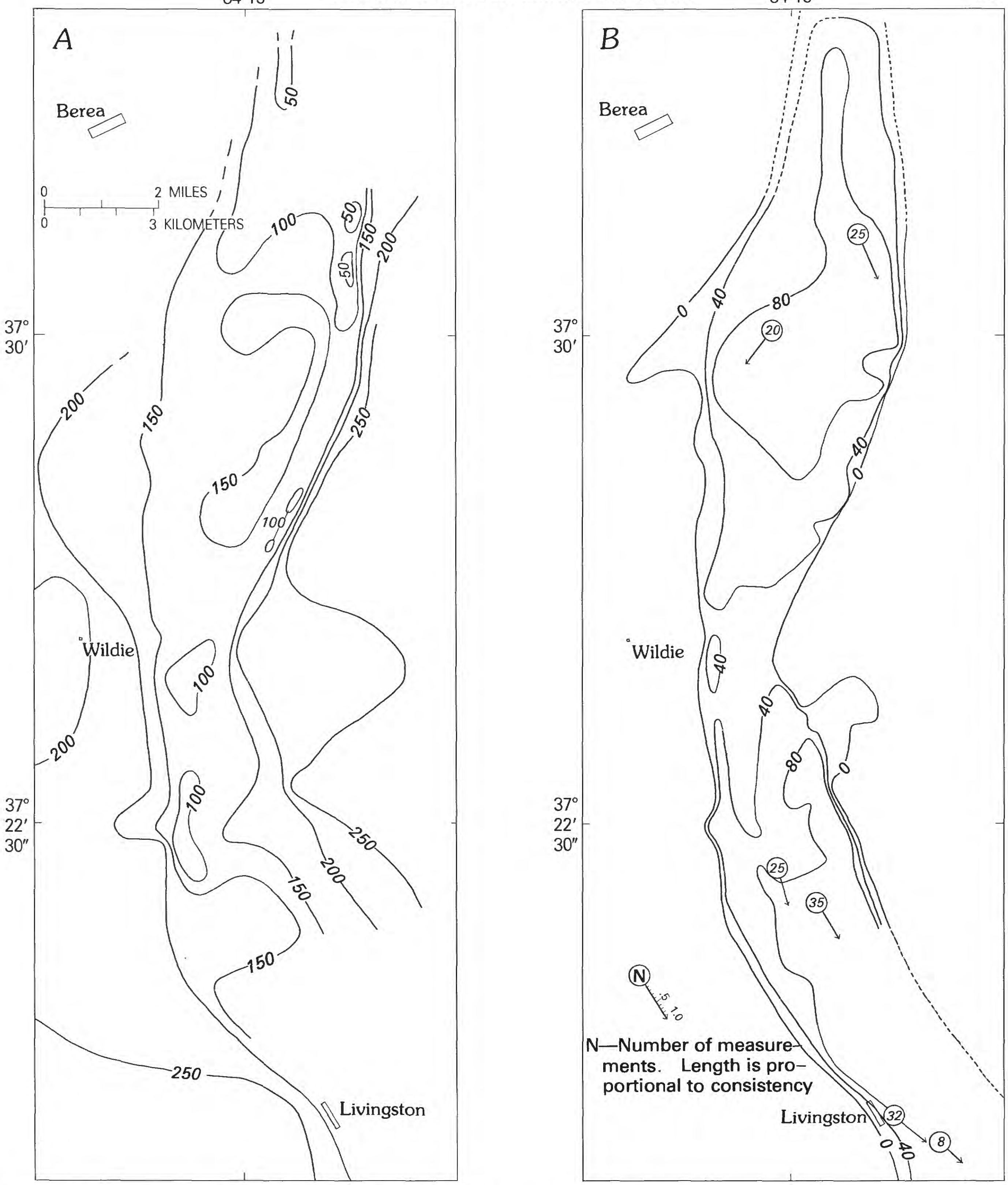


FIGURE 20.—Contour maps showing channel and channel fill of the Livingston Conglomerate member of the Lee Formation. *A*. Map of the Livingston channel as shown by thickness contours of the combined Newman Limestone and Pennington Formation (Mississippian). Contour interval 50 ft. *B*. Map showing thickness contours of the Livingston and resultants of dip-directions of crossbeds calculated using methods of Curray (1956). Contour interval 40 ft. Length of resultant of dip-directions of crossbeds is proportional to consistency of measurements (vector sum: number of measurements).

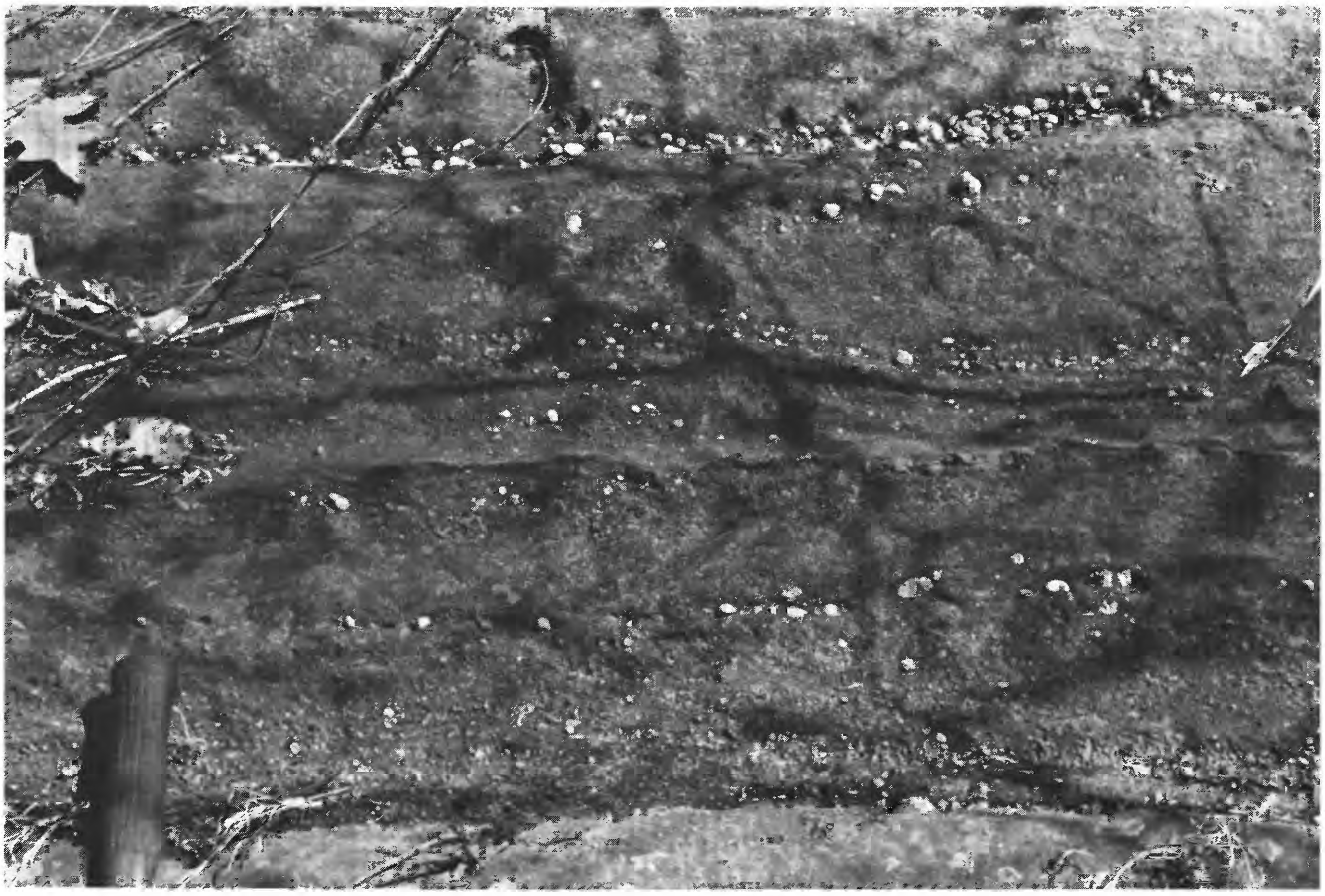


FIGURE 21.—Planar sets of beds in the Livingston Conglomerate Member showing stringers and lenses of pebbles along bedding planes.

In some areas east and northeast of Clay City (see fig. 3), karst developed in the Newman Limestone in Late Mississippian or Early Pennsylvanian time. Sink holes in the upper surface of the limestone unit trapped pebbly sandstone in Early Pennsylvanian time (Weir, 1974a, b; Hoge, 1977). Conglomerate and sandstone in the sink holes and the previously described paleochannels are commonly stained reddish brown to light brown by iron carbonate and iron oxide cement. Iron-impregnated molds and casts of large stems and fragments of bark occur sparsely in these rocks.

Small paleochannels that drained to the southeast toward the subsiding Appalachian basin were formed at the same time as the larger channels. The small channels, because they lack thick deposits of coarse clastics, have generally not been mapped. They are inferred to occupy lows on the sub-Pennsylvanian surface (fig. 4). One small paleochannel with several of its tributaries has been traced about 10 mi across parts of the Soldier, Olive Hill, and Ault quadrangles (Englund and Windolph, 1971, fig. 3). The channel, as much as 40 ft deep, is largely filled with shale and siltstone but, in places, has a basal bed of poorly sorted pebbles and boulders of locally derived chert, sandstone, and limestone as much as 3 ft thick.

ROCKCASTLE CONGLOMERATE MEMBER OF THE LEE FORMATION

The Rockcastle Conglomerate Member crops out along the southern part of the Pottsville Escarpment in Kentucky (fig. 17). Campbell (1898a, b) named the Rockcastle Conglomerate (Lentil) from exposures along the Rockcastle River west and southwest of London, Ky. This member, like other sandstone members of the Lee, is quartzose, fine to coarse grained, and contains well-rounded quartz pebbles up to 5 in. but more commonly about 0.3 in. in diameter. Lenses of pebble conglomerate are most common near the base of the member, which is an irregular surface cut into underlying strata. The sandstone is characterized by medium- to large-scale trough sets of crossbeds that indicate a dominant southwesterly current direction. The member thins or splits into tongues to the northwest and pinches out in that direction into siltstone and shale or grades into very fine to fine-grained, ripple-bedded sandstone. The uppermost beds grade upward from coarser to finer-grained sandstone and commonly grade into siltstone. The southeastern margin of the Rockcastle is not exposed. The Rockcastle is a cliff-forming unit that in places is more than 200 ft thick but over much of the outcrop area is about 100 ft thick.

The Rockcastle and the Livingston Conglomerate Members do not crop out in the same area, but the base of the Rockcastle at its northwestern edge of outcrop is estimated to be about 150 ft or more above the Livingston. Cross section C–C′ of figure 25 shows the relation of the Rockcastle to a channel-fill sandstone at the base of the Pennsylvanian strata that is similar to the Livingston. The Rockcastle has been traced southwestward into Tennessee where, in terms of the nomenclature used by the Tennessee Division of Geology, it is probably equivalent to only the upper part of the Rockcastle of the Crab Orchard Mountains Group.

The lower part of the Rockcastle is correlated by Englund (1968, p. 18) with the Naese Sandstone Member of the Lee Formation of the eastern part of the coal field. This correlation suggests that the Rockcastle is probably of Early and Middle Pennsylvanian age (Rice, 1978, p. A109).

UNNAMED QUARTZOSE SANDSTONE UNITS BELOW THE CORBIN SANDSTONE MEMBER ALONG THE POTTSVILLE ESCARPMENT

Unnamed ledge- and cliff-forming sandstone units, some more than 100 ft thick, are interstratified with named members of the Lee along the Pottsville Escarpment. Most of the thicker units are confined to the southern part of the outcrop belt. Sandstone in these

FIGURE 22.—View of the western edge of a quartzose sandstone- and conglomerate-filled channel cut into the Newman Limestone near the southern edge of the Alcorn quadrangle (Rice, 1972). Maximum thickness of sandstone and conglomerate is about 30 ft and it extends to the east (right hand side of photo) about 0.4 mi. Channel is in the central part of a north-south oriented paleovalley that is about 2 mi wide and 180 ft deep.

units is commonly quartzose, crossbedded, in part sparsely micaceous, fine- to medium-grained, and locally contains well-rounded pebbles of quartz and grades to conglomerate. Some sandstone units contain lenses of thin-bedded siltstone and silty shale as much as 15 ft thick. The sandstone units commonly have sharp bases scoured into shale and siltstone. The sandstone units grade upward and laterally into ripple-bedded sandstone or siltstone and shale. Studies of dip directions of crossbeds in some of these units by Blancher (1970, p. 17) and the authors indicate that the dominant current direction was to the southwest. Only sparse fossils are noted in these units and include casts of woody material and fine carbonaceous flakes. The sandstone units appear to be migrating regionally nonpersistant channel-fill deposits. In the GQ Maps published before 1973, these sandstone units generally were mapped as part of the Lee; in later reports, the units were shown to intertongue with and grade into the Breathitt Formation and were included in the Breathitt.

CORBIN SANDSTONE MEMBER OF THE LEE FORMATION

The Corbin was named from exposures near Corbin, Ky., where it is as much as 130 ft thick (Campbell, 1898a, b). The sandstone, which weathers pink to grayish orange, is generally coarse grained at the base and grades irregularly to fine grained at the top. It contains lenses of pebbles. Rounded pebbles as much as 2 in. in diameter are present, but most pebbles are less than 0.5 in. in diameter. In general, both the number and the diameter of pebbles increase northeastward along the length of the sandstone body.

The Corbin is the most widespread Lee sandstone unit cropping out in eastern Kentucky (fig. 26). It is exposed along almost the full extent of the Pottsville Escarpment (fig. 17). It pinches out to the northwest in northeastern Kentucky near Olive Hill, Ky. It extends eastward into the subsurface and is brought to the surface by uplift along faults in two small areas west of Paintsville, Ky. It pinches out to the southeast in the central and southern parts of the outcrop belt and ex-

FIGURE 23.—Massive quartz-pebble conglomerate on Pilot Knob in the Levee quadrangle (McDowell, 1978).

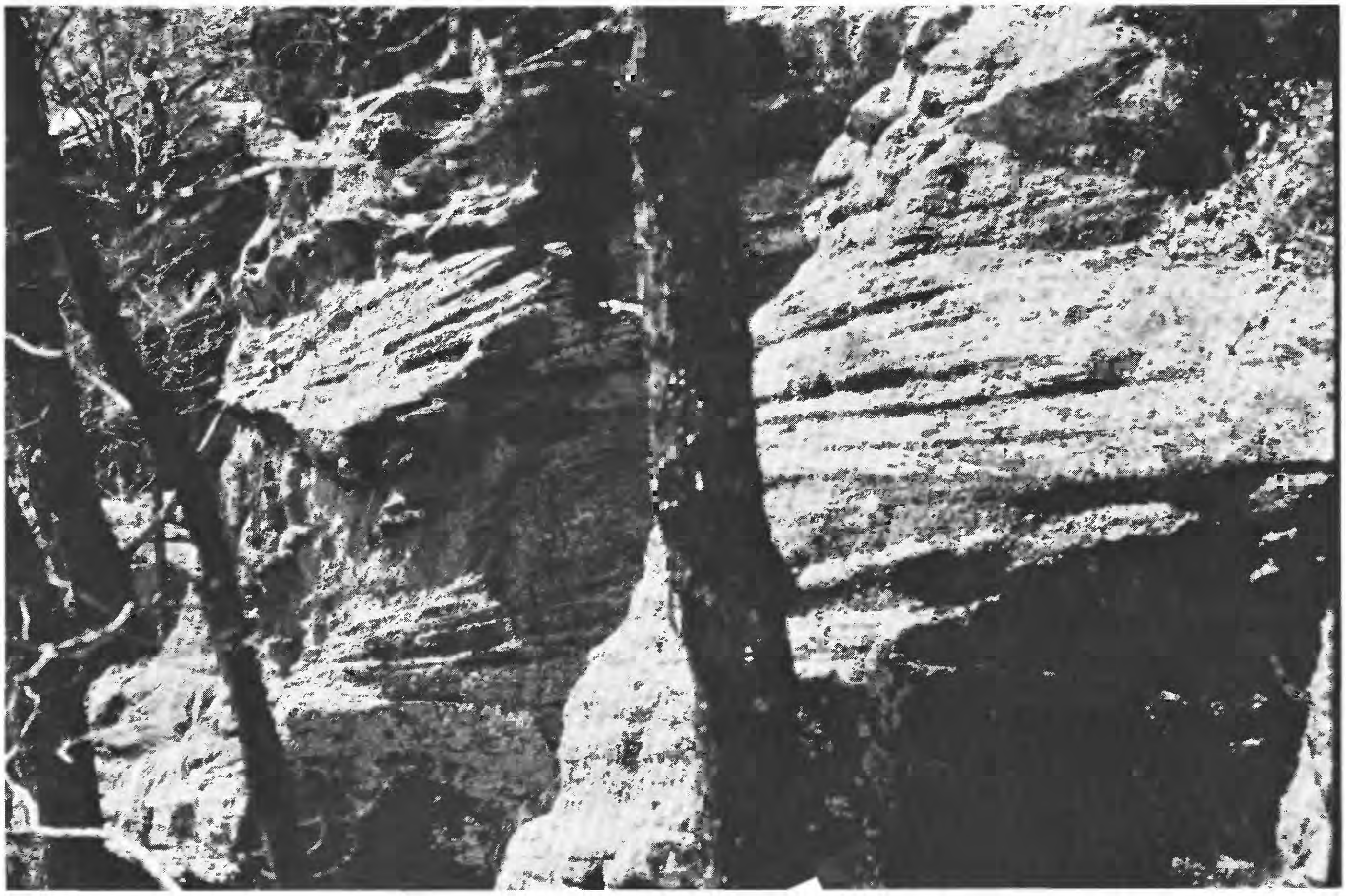


FIGURE 24.—Crossbedded conglomerate and conglomeratic sandstone on Pilot Knob in the Levee quadrangle (McDowell, 1978).

tends southwestward into Tennessee. As shown in figure 27, the Corbin is generally less than 200 ft thick but attains a thickness of 250 ft in the Pomeroyton and Slade quadrangles east of Richmond, Ky. (Weir, 1974b; Weir and Richards, 1974).

The basal contact of the Corbin is sharp and irregularly wavy and has relief of as much as 100 ft in a distance of 2,000 ft. Deep scours that underlie the contact trend subparallel to the westerly or southwesterly current directions indicated by the dip directions of crossbeds (fig. 28). In the northern part of the outcrop belt, the Corbin is at or near the base of the Pennsylvanian stratigraphic section and commonly fills channels eroded into Newman Limestone. To the south, older underlying Pennsylvanian strata thicken so that at the Tennessee border the Corbin is as much as 700 ft above the base of the Pennsylvanian. Along the southeastern pinchout edge of the Corbin, the basal contact commonly climbs stratigraphically and the unit thins abruptly along the side of the deposit and feathers out in shale and siltstone. The Corbin grades laterally in many places to lenses of light-brown- to pink-weathering, locally rooted, fine-grained sandstone as much as 20 ft thick and several miles wide (Black, 1977; Haney and Rice, 1978). These lenses of sandstone probably represent flood plain deposits adjacent to the channels in which the Corbin river system flowed. The Corbin along its pinchout edge and at its top commonly intertongues with siltstone and shale or grades into ripple-bedded fine-grained sandstone. The member contains a few lenses of shale and siltstone and, rarely, thin coal beds. The only fossils observed in the member are coalified or iron-impregnated plant fragments.

Most of the Corbin Sandstone Member is in planar and trough sets, as much as 10 ft thick, of low- to high-angle crossbeds (fig. 29). Figure 28 shows the dip directions of crossbeds in the Corbin, which were averaged by the use of the trignometric methods suggested by Curray (1956). All areas of the outcrop belt were not sampled, but the data indicate that the current directions generally parallel the long axis of the outcrop belt of the Corbin. This parallelism is most apparent in the

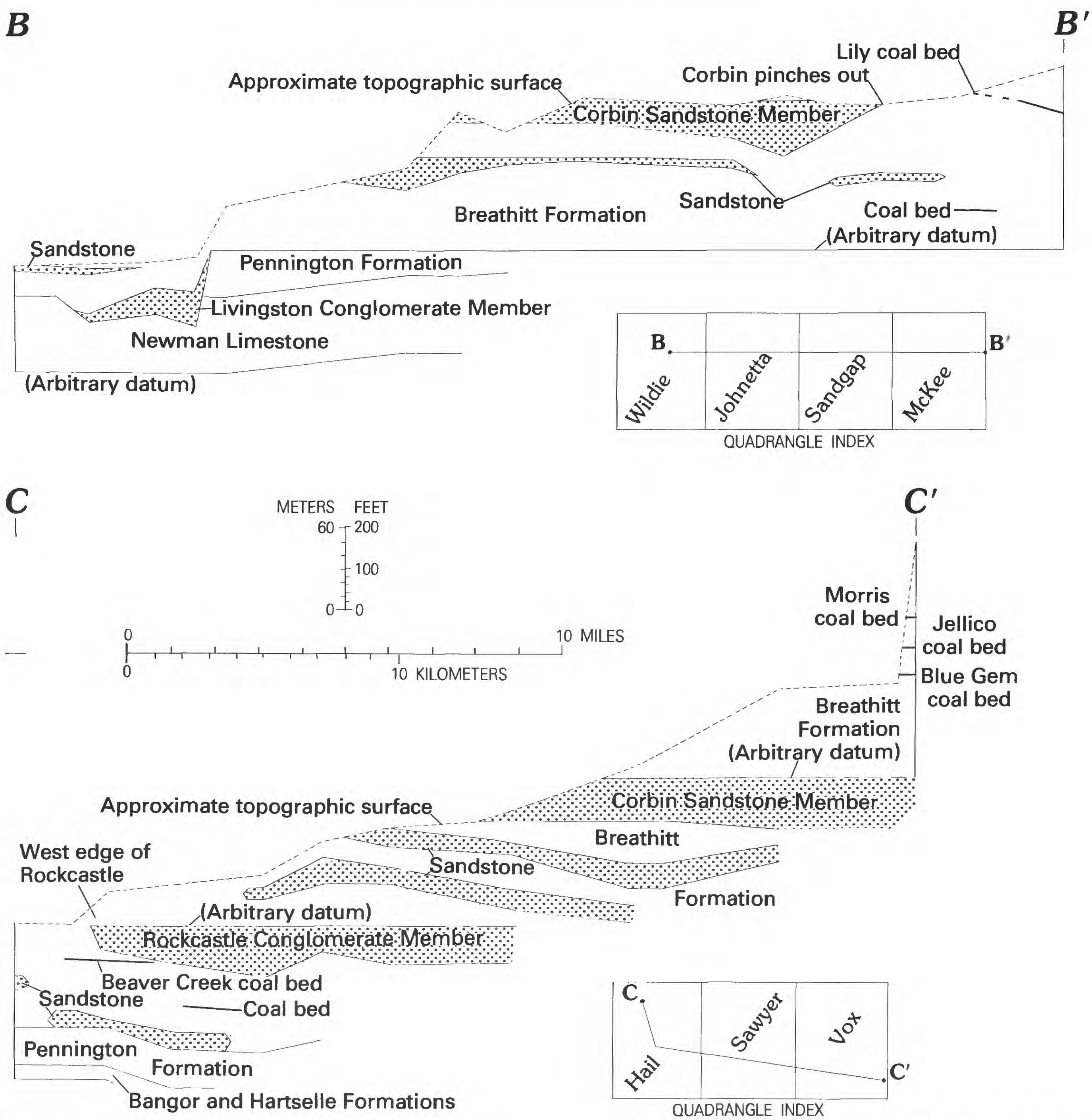


FIGURE 25.—Cross sections showing the relation of quartzose sandstone and conglomeratic-sandstone units in the lower part of the Pennsylvanian sequence near the west edge of the Cumberland Plateau in eastern Kentucky. All Pennsylvanian strata except the Livingston Conglomerate, Rockcastle Conglomerate, and the Corbin Sandstone Members of the Lee Formation are assigned to the Breathitt formation. Unlabeled strata consist of shale, siltstone, and subgraywacke. See figure 17 for location of sections; figure 1 shows quadrangle location.

FIGURE 26.—Cliffs of the Corbin Sandstone Member of the Lee Formation north of Beattyville, Ky., in Natural Bridge State Park on Kentucky State Highway 11.

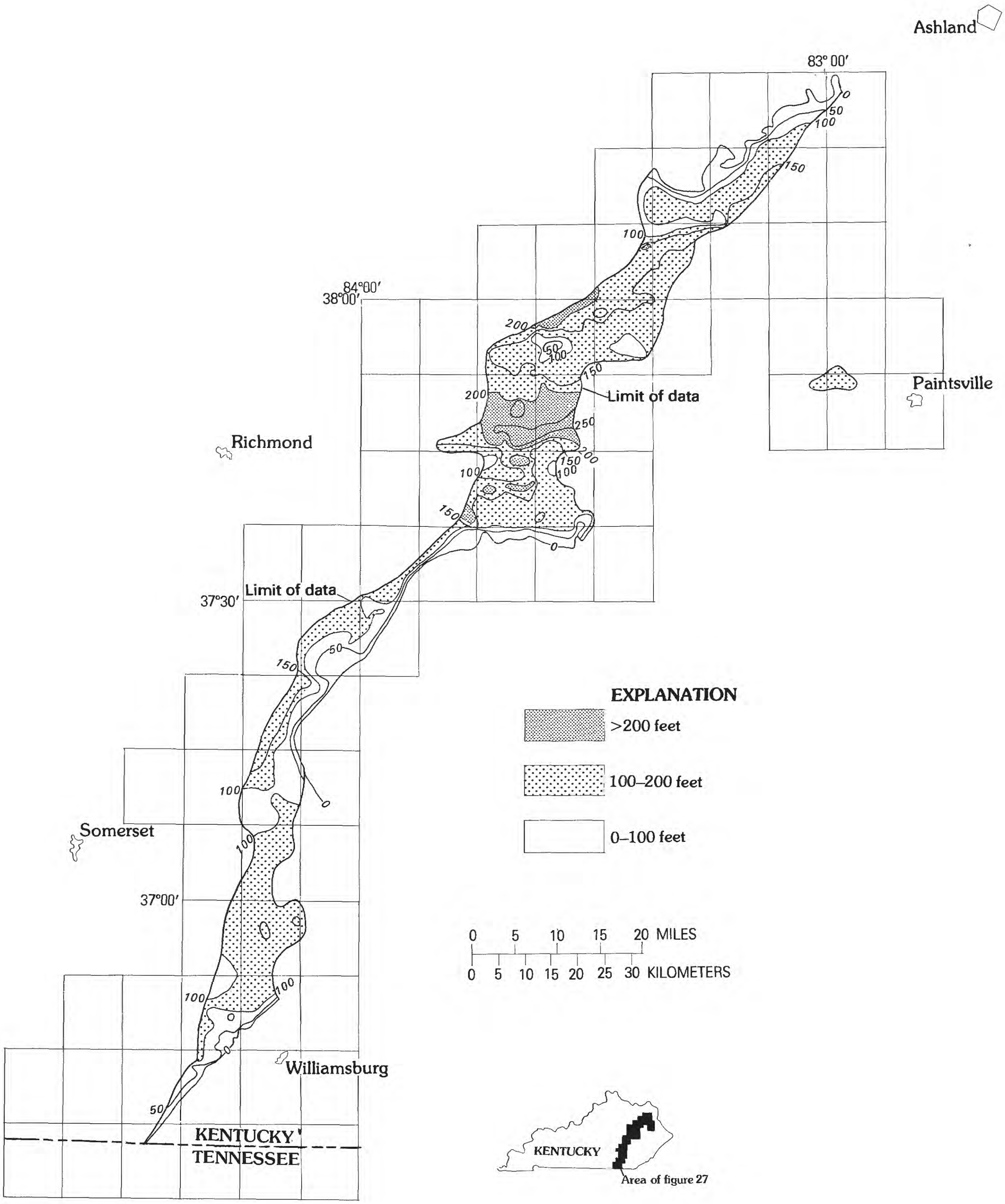
southern part of the outcrop belt in which the currents inferred from the dip directions of crossbeds are subparallel to the southeastern depositional edge of the member. In the northern part of the outcrop belt, the eastern continuation of the Corbin is supported by the inferred current directions (fig. 28) as well as thickness contours (fig. 27).

The Corbin Sandstone Member was interpreted by Wanless (1975a, table 2, p. 28) as being equivalent to the Rockcastle Sandstone of the Crab Orchard Mountains Group in Tennessee. As shown in the foregoing discussion, the Rockcastle Conglomerate Member of the Lee Formation underlies the Corbin and is partly or wholly equivalent to the Rockcastle Sandstone in Tennessee. Mapping in Kentucky has also shown that the Corbin extends into northeastern Kentucky where it lies stratigraphically above the Olive Hill clay bed and its equivalent, the Sciotoville clay member of the Pottsville Formation in Ohio. The Corbin is, therefore, probably equivalent to the Massillon sandstone member of the Pottsville in Ohio which overlies the Sciotoville and is also equivalent to the Lower Connoquenessing sandstone member of the Pottsville in western Pennsylvania. These stratigraphic relations supported by analyses of plant spores in coal beds underlying the Corbin (Rice, 1978) show that the Corbin is Middle Pennsylvanian in age.

GRAYSON SANDSTONE BED OF WHITTINGTON AND FERM

The name Grayson was given to a thin ganister like sandstone bed that directly underlies the Wolf Creek or Bruin coal bed near Grayson in northeastern Kentucky. In its type area, the sandstone is very fine grained, quartzose, slightly micaceous, bioturbated and contains stigmarian rootlets. Near Grayson, the bed is only 0 to 5 ft thick and forms a conspicuous minor ledge that on weathering yields blocky float.

The Grayson crops out mainly in Carter County and adjacent parts of Greenup and Elliott Counties (figs. 3 and 17). The bed was assigned to the Breathitt Formation by Whittington and Ferm (1967), but west of Grayson, where the unit is as much as 70 ft thick, it


Ashland
83° 00′
84°00′
38°00′
Paintsville
Richmond
Limit of data
37°30′
Somerset
37°00′
Williamsburg
KENTUCKY
TENNESSEE
EXPLANATION
>200 feet
100–200 feet
0–100 feet
0 5 10 15 20 MILES
0 5 10 15 20 25 30 KILOMETERS
KENTUCKY
Area of figure 27

was assigned by DeLaney and Englund (1973) to the Lee Formation. The thicker part of the Grayson appears to have been deposited in a southwesterly trending 4-mi-wide channel that locally has been scoured into Mississippian shale (Englund and Windolph, 1975). Sandstone in the channel is quartzose, which is very fine to coarse grained, pebbly to conglomeratic, and has well-rounded quartz pebbles as much as 0.5 in. in diameter. As is characteristic of the Grayson, the upper surface of the channel facies is rooted. Where the Grayson outcrop belt overlaps the Corbin Sandstone Member, the Grayson lies from a few feet to as much as 80 ft above the Corbin.

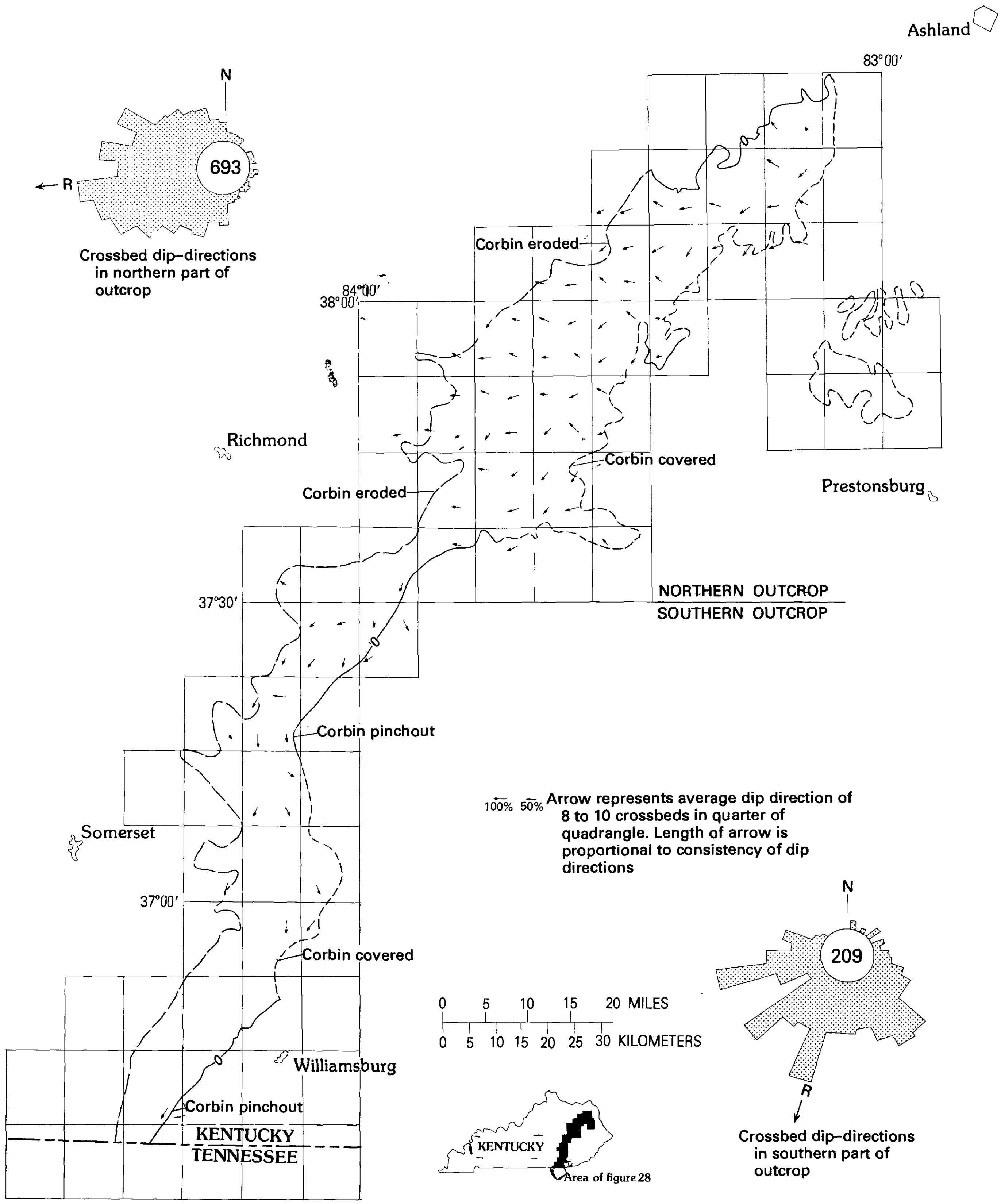
ENVIRONMENT OF DEPOSITION OF SANDSTONE UNITS IN THE LEE FORMATION

Sandstone units of the Lee Formation are characteristically quartz rich and range from more than 90 percent to more than 99 percent quartz. The sandstone units are relatively coarse grained, commonly pebbly, and in places conglomeratic. They are southwest-trending linear or broadly lobate bodies. By the use of these characteristics, some geologists (Ferm, 1974; Horne and others, 1974; Miller, 1974; Hayes and Connor, 1982) inferred that the sandstone units were deposited in a beach or barrier-bar environment with land to the southeast and sea to the northwest. These workers further suggested that the clastics in the Lee deposits were transported into nearshore environments by westward- or northwestward-flowing streams that drain emerging land areas in the central Appalachians parallel to and southeast of the trough of the Appalachian basin. In the high energy nearshore environments, wave action could have eliminated the less stable minerals and finer clastic fractions (Horne, 1979). The general southwestward current direction implied by crossbedding in the Lee sandstone units was ascribed to longshore currents and southwestward migration of tidal channels.

This shoreline model of deposition is, however, only possibly applicable to sandstone units that are associated with marine rocks. Such an association in the Lee Formation is true only of the lower tongues in the eastern outcrops, the Pinnacle Overlook, Chadwell, and White Rocks Sandstone Members of the Lee; in the western outcrops, the Carter Caves Sandstone is a Lee-type sandstone also associated with marine rocks. These sandstone units are interbedded with siltstone and shale that contain marine fossils. Furthermore, they have characteristics of marine deposition, such as transitional as well as disconformable bases and a dominance of ripple-bedding and bimodal crossbedding (BeMent, 1976). The environments of deposition of these members, however, are uncertain, for the distribution and geometry of these sandstone units are very poorly known. The Carter Caves Sandstone (Mississippian) in northeastern Kentucky has been attributed to deposition in a beach or barrier bar by Ferm and others (1971), in an off shore bar by Englund and Windolph (1971), and in a tidal channel by Ettensohn (1977).

Many geologists postulate a fluvial or continental environment for the Pennsylvanian Lee-type sandstones in the central Appalachian and Eastern Interior basins. Among the definitive characteristics are the following: the disconformable bases and multistory nature of the sandstones, the fining upward of grain size, the dominance of planar and trough crossbedding, and the common occurrence of coalified plant remains and impressions of plants in the deposits (Fuller, 1955; Mrakovich, 1969; Englund, 1968, p. 17; BeMent, 1976; Wixted, 1977; Houseknecht, 1978; Pryor and Potter, 1979). Most studies recognize the differences between the moderately well sorted quartzose sandstones of the Lee members and the poorly sorted clayey and silty sandstones of the enclosing units and note that the Lee sandstone is much coarser, locally contains abundant quartz pebbles, and thus could not have been derived from the enclosing units. The two types of sandstones seem to have been derived from different sources. The quartz grains and pebbles of the quartzose sandstone units are commonly well rounded. Overgrowths on the rounded quartz grains, indicative of previous cycles of deposition, suggest they were derived from pre-existing unmetamorphosed sediments from which the less stable minerals had been removed by weathering (Siever and Potter, 1956, p. 328). The finer-grained subgraywackes, on the other hand, contain angular to sub-rounded grains of quartz and feldspar, conspicuous mica, and small fragments of schist and igneous rocks, which suggest that the sediments were derived from a low- to medium-grade metamorphic terrane (Houseknecht, 1978, p. 159). Those and other petrographic differences of the two types of sandstone were combined with regional paleocurrent studies in Pennsylvania by Meckel

FIGURE 27.—Generalized thickness contours of the Corbin Sandstone Member of the Lee Formation. Contours dashed where conjectural. Contour interval 50 ft. The Corbin is at least 180 ft thick in the eastern outcrop areas just west of Paintsville, but insufficient data do not allow thickness contours to be drawn.



Ashland
83°00′
N
R
693
Crossbed dip-directions in northern part of outcrop
Corbin eroded
84°00′
38°00′
Richmond
Corbin covered
Prestonsburg
Corbin eroded
NORTHERN OUTCROP
SOUTHERN OUTCROP
37°30′
Corbin pinchout
100% 50% Arrow represents average dip direction of 8 to 10 crossbeds in quarter of quadrangle. Length of arrow is proportional to consistency of dip directions
Somerset
37°00′
N
209
Corbin covered
0 5 10 15 20 MILES
0 5 10 15 20 25 30 KILOMETERS
Williamsburg
Corbin pinchout
KENTUCKY
TENNESSEE
KENTUCKY
Area of figure 28
R
Crossbed dip-directions in southern part of outcrop

(1970, p. 60, table 2), who suggested that the finer-grained subgraywacke was derived from a tectonic source area to the southeast and the coarser grained quartzose sandstone from a cratonic source area to the north and northeast.

PALEOGEOGRAPHY

In Late Mississippian time, uplift to the east and southeast in the Appalachian orogenic belt exposed older Paleozoic deposits of quartzose sandstone and conglomerate to erosion. Streams periodically transported those coarse clastics across extensive tidal flats into shallow marine environments where they were reworked by waves and marine currents and were deposited as the Pinnacle Overlook, Chadwell, and White Rocks Sandstone Members of the Lee Formation. At the same time, regional uplift caused thinning of sedimentary units toward the north in northern Kentucky and adjacent areas; local erosion as well as probable nondeposition was responsible for the northward truncation of some Upper Mississippian units. As uplift continued, a large area in North America became emergent as is indicated by the occurrence of entrenched Lower Pennsylvanian fluvial channel deposits in the Mississippian strata in both the Appalachian and Eastern Interior basins. Regional current data and petrographic studies of basal Pennsylvanian sandstone units by Potter and Siever (1956a) have shown that the Late Mississippian-Early Pennsylvanian paleoslope was toward the south-southwest in much of the north-central and northeastern United States and that streams in Early Pennsylvanian time carried sediment from as far as the eastern portions of the Canadian Shield and northern Appalachians into and beyond the Eastern Interior basin. Although much of that land surface has been destroyed by post-Paleozoic erosion, a large part of it has been preserved beneath the overlying Pennsylvanian strata.

The outcrop limits of the Pennsylvanian rocks and the limits of underlying Mississippian carbonate formations in the central part of the Appalachian basin and in part of the Kentucky portion of the Eastern Interior basin are shown in figure 30. The underlying carbonate formations are Upper Mississippian in age and include strata of the Newman Limestone in Kentucky, the Maxville Limestone in Ohio, and the Greenbrier Limestone in Virginia and West Virginia; in south-central and western Kentucky equivalent strata consist largely of the St. Louis and St. Genevieve Limestones. These limestone units are continuous and are the most resistant units in the Mississippian section along the northwestern flank of the Appalachian basin. The limestone units were tilted southeastward toward the subsiding Appalachian basin near the end of Mississippian time and formed a northwest-facing escarpment or cuesta that extended from western Pennsylvania into central Kentucky (fig. 30). This cuesta was a significant physiographic feature in the landscape in Late Mississippian and Early Pennsylvanian time, for along much of its length it was the drainage divide between the Appalachian and Eastern Interior basins.

FIGURE 29.—Trough sets of crossbeds in the Corbin Sandstone Member of the Lee Formation near Beattyville, Ky.

Figure 31 shows the location of some Pennsylvanian channel-fill deposits in Pennsylvania, Ohio, and western Kentucky. Areas of lag gravels derived from conglomeratic channel-fill deposits of Pennsylvanian age that rest on strata of Mississippian age on hilltops in central Kentucky are also shown. Inferred current directions, indicated by arrows, are generalized from the work of Meckel (1967) for the Olean Conglomerate Member of the Pottsville Formation in Pennsylvania, from Coogan and others (1974) for the Sharon outcrops in northern Ohio, from Couchot (1972) for outcrops of the Sharon Member of the Pottsville Formation in southern Ohio, and from Pryor and Potter (1979) for

FIGURE 28.—Outcrop pattern and resultants of dip-directions of crossbeds of the Corbin Sandstone Member of the Lee Formation. Resultants, shown by arrows, are vector sums of 5 or more dip directions in one-quarter of a quadrangle, calculated using the trignometric methods suggested by Curray (1956). Rose diagrams indicate frequency distribution and total number of measurements.

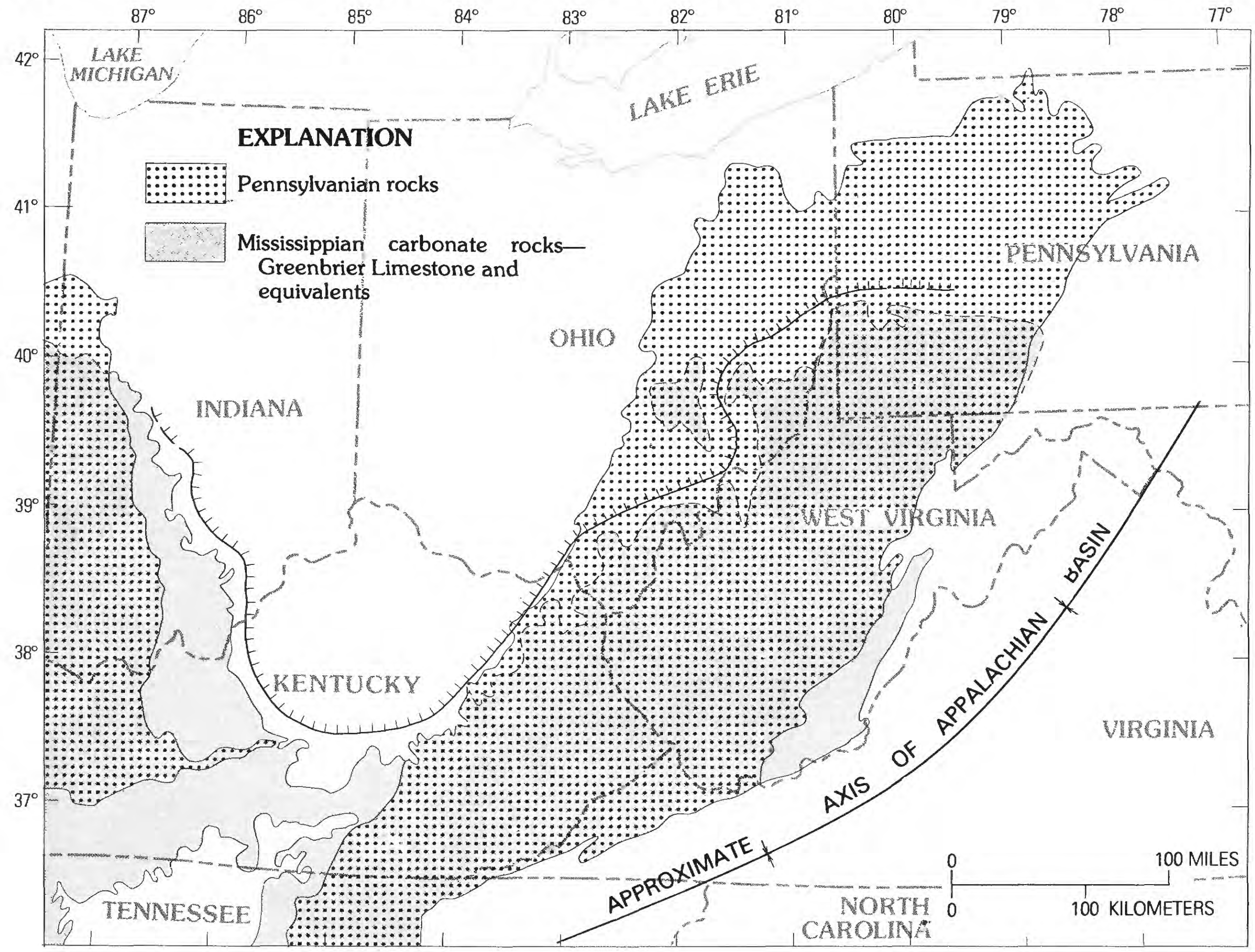


FIGURE 30.—Map of Kentucky, Ohio, West Virginia, and part of Virginia showing limits of outcrop of Pennsylvanian rocks and limits of distribution of Upper Mississippian carbonates (the Newman, Maxville, and Greenbrier Limestones). Subsurface data mainly from Craig, Connor, and others (1979, pl. 6B; also Flowers [1956] for West Virginia and Lamborn [1945] for Ohio). Hachured line indicates the approximate position in Late Mississippian to Early Pennsylvanian time of an escarpment or cuesta capped by Upper Mississippian carbonate units.

the outcrops of the Caseyville Formation in the Brownsville paleovalley in western Kentucky. Coarse clastics in the Brownsville paleochannel were undoubtedly derived from Appalachian sources (Pryor and Potter, 1979, p. 59). In central Kentucky, lag gravels capping hilltops were derived from Pennsylvanian conglomerate units (fig. 31). These gravels were interpreted by Miller (1910) and Burroughs (1923) to be a residual lag from Lower Pennsylvanian channel deposits which were continuous across the Cincinnati Arch into western Kentucky. Although areas of channel deposits in figure 31 are widely separated, this report postulates that they were parts of a southwest-flowing drainage system on the northwest side of the Mississippian carbonate cuesta.

The history of the quartzose sandstone deposits characteristic of the Pennsylvanian portion of the Lee Formation began in Late Mississippian time with the cutting of channels by largely southwest-trending drainage systems. In Middle Pennsylvanian time, the last remnants of the channels and their fills were buried by finer grained sediments from what was probably more easterly or southeasterly sources. A sketch of the Pennsylvanian depositional events recorded by the rocks of the Lee Formation follows.

Stage 1.—During stage 1, the sub-Pennsylvanian drainage pattern in Kentucky and the central Appalachian basin was established. Figure 32 is a schematic synthesis of inferred stream channels at the end of Mississippian time. Streams radiated away from the Jessamine Dome of the Cincinnati Arch in northern Kentucky. The master river connecting the Sharon and Brownsville paleovalleys appears to have been deflected southward around the dome, and as suggested by the nearby lag gravels derived from basal Pennsylvanian conglomerates, it probably eroded through the Cincinnati Arch and the carbonate cuesta along the down-thrown south side of the east-west trending Brumfield fault zone (fig. 7) in south-central Kentucky. North-flowing tributaries to the Sharon system in Ohio near the West Virginia border are indicated by the subsurface studies of Flowers (1956). A large paleovalley in the easternmost part of Kentucky and the presence of thick sandstone units in the basal Pennsylvanian of adiacent West Virginia suggest a major river system flowed southwestward across the central part of West Virginia and through eastern Kentucky. To the southeast of the paleovalley, studies by Englund (1974) and Miller (1974) indicate that the earliest Pennsylvanian sediments were deposited northwest- to westward in several merging deltaic lobes.

Stage 2.—Uplift of the craton and mountain building in the Appalachian orogenic belt, which began in Late Mississippian time and continued into Pennsylvanian time, resulted in an increase in erosion. In the northern part of the belt, outcrops of older Paleozoic sedimentary and metamorphic rocks yielded quartz sand and gravel that were carried to the southwest by rivers that drained the region. As the volume of sediments increased, the streams filled their channels, became braided, and spread out across their flood plains. Streams periodically breached gaps in the Mississippian

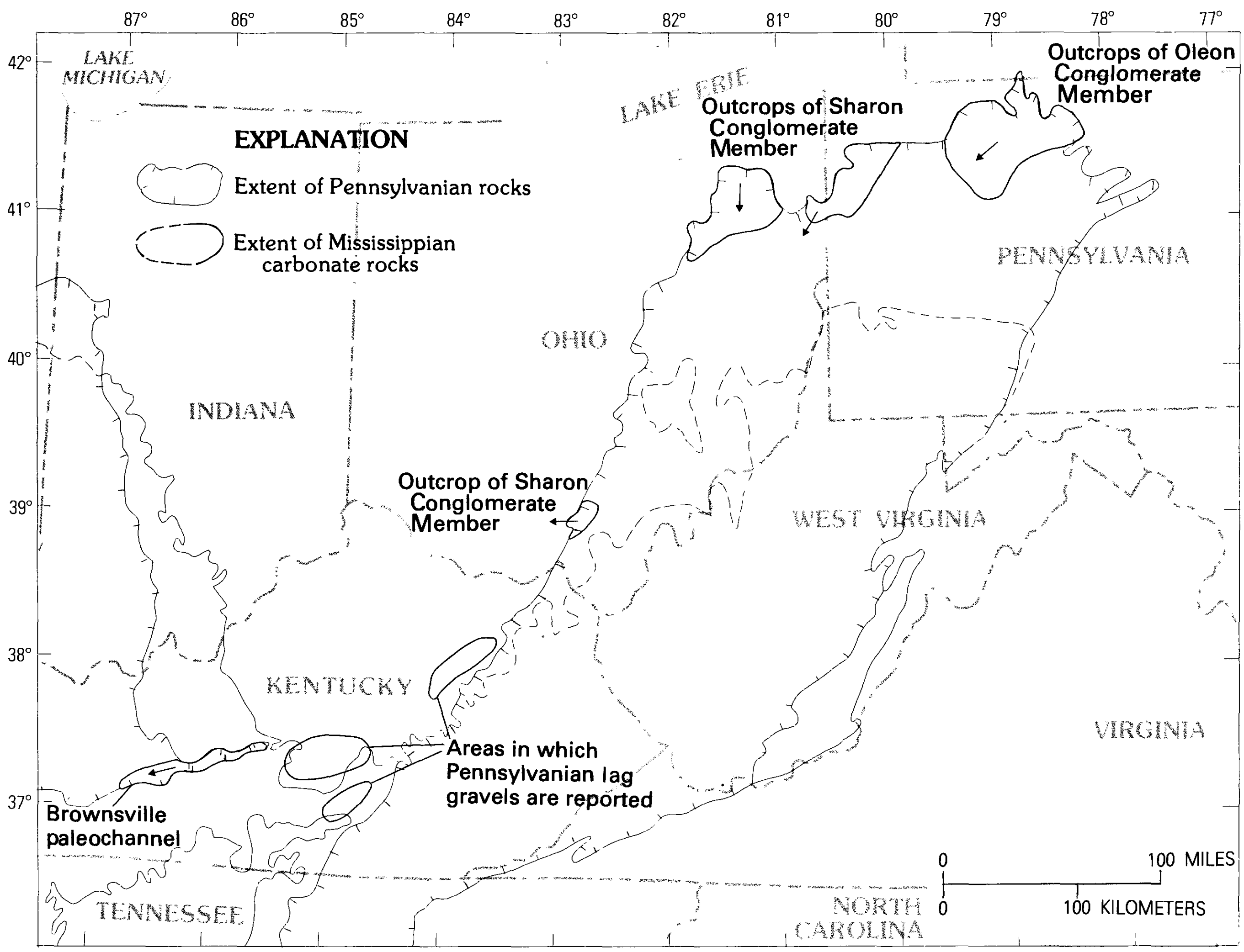


FIGURE 31.—Pennsylvanian sandstone- and conglomerate-filled channels cut into Mississippian strata in Ohio, Pennsylvania (Olean and Sharon Conglomerate Members), and western Kentucky (Caseyville Formation). Areas of lag gravels derived from conglomerate units of Pennsylvanian age are also shown.

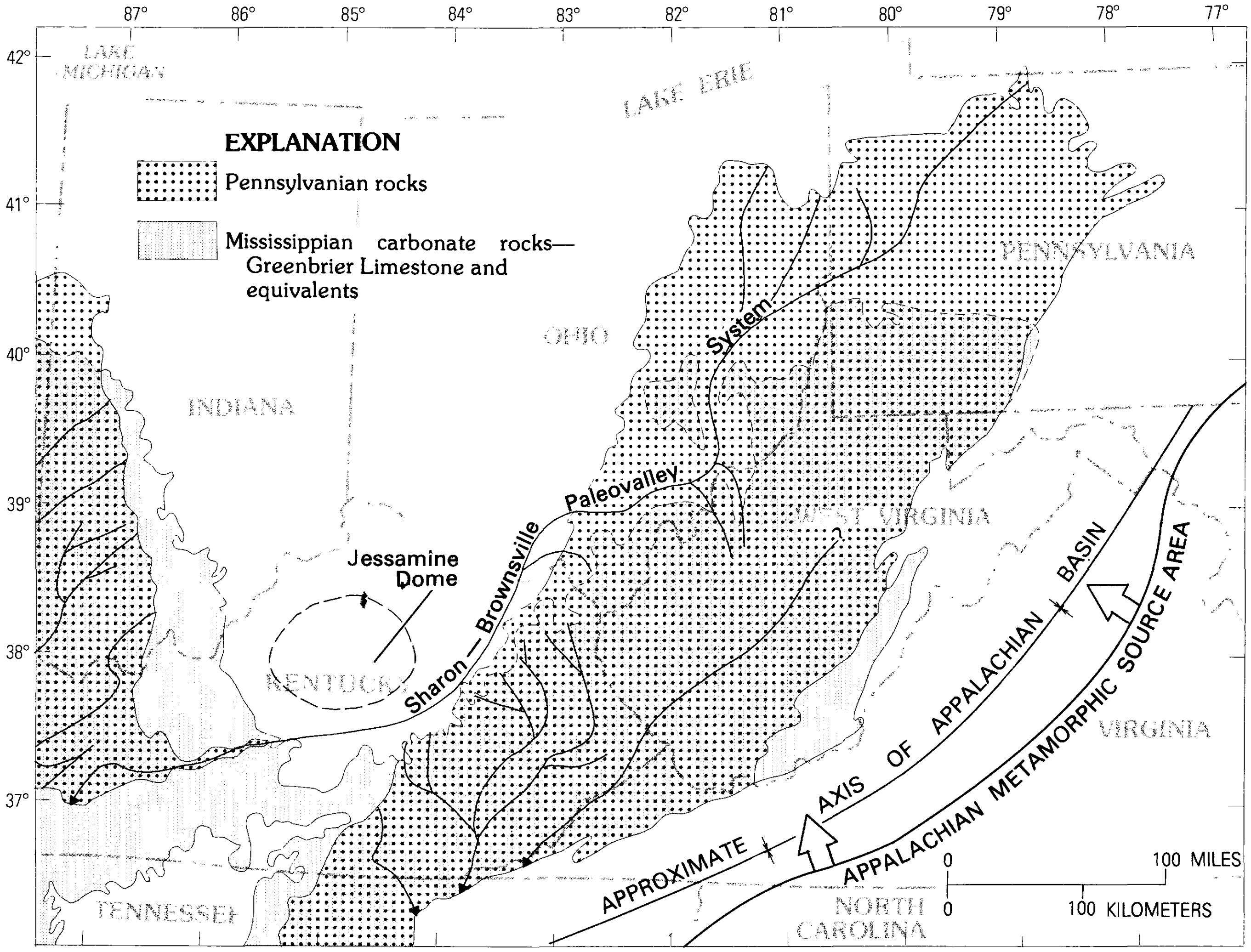


FIGURE 32.—Map of Kentucky, Ohio, West Virginia, and parts of adjacent states showing the inferred Late Mississippian-Early Pennsylvanian drainage system in which channel-fill quartzose sandstone and conglomerate were deposited. (Compare data shown in figures 4, 13, and 31).

carbonate cuesta in at least five places, resulting in the deepening of channels of some streams on the back or southeast side of the cuesta (fig. 33).

East of Kentucky, the Appalachian uplift exposed mostly fine-grained metamorphic rocks whose detritus of quartz, feldspar, mica, and rock fragments was transported westward and northwestward into the southeastern margin of the subsiding Appalachian basin. The axis of the Appalachian basin, where the greatest subsidence took place in Early Pennsylvanian time, lay southeast of the present outcrop area and has been eroded away. Deposition of fine-grained clastics into and across the basin was apparently continuous from latest Mississippian to earliest Pennsylvanian time. This resulted in an intertonguing of lithologies and apparent conformability of strata across the Mississippian-Pennsylvanian systemic boundary in that area (Englund, 1974). Strata representing those earliest Pennsylvanian deposits belong to the Pocahontas Formation which crops out in southeastern West Virginia and southwestern Virginia (fig. 33). The Pocahontas thins to the northwest and may locally onlap older Mississippian rocks in that direction. Near the end of this stage, distal deposits of the Pocahontas were truncated by the southwest-flowing river in West Virginia and Kentucky that began the deposition of the Middlesboro Member of the Lee Formation.

Stage 3.—During stage 3, aggradation and floods in the Sharon-Brownsville valley led to significant changes in the drainage system. The breaching of the drainage divide between the Appalachian and Eastern Interior basins (fig. 33) resulted in major stream captures (fig.

34). Upwarping of the Cincinnati and Waverly Arches (see fig. 7) or regional subsidence may have contributed to the changes in the stream pattern.

In south-central Kentucky, floods carried sand and gravel from the Sharon-Brownsville river system across the former uplands of the cuesta and through some of the low gaps into streams draining into the Appalachian basin. The Livingston channel was widened and deepened by a stream whose headwaters captured the middle part of the Sharon-Brownsville river system. Reworking of gravels from the captured valley produced the thick zone of large pebbles in the upper part of the Livingston Conglomerate Member of the Lee Formation described by Wixted (1977, p. 50, fig. 5).

In eastern Ohio, the Sharon drainage flowed south into central West Virginia and joined a major river which flowed to the southwest. The water gap in the Mississippian cuesta near the Ohio–West Virginia border was widened and deepened. Flowers (1956, p. 2) shows this valley where it cuts into the Greenbrier Limestone to have a width of about 14 mi, a length of 85 mi, and a depth of about 200 ft.

Stage 4.—During stage 4, the major river channel in southeastern Kentucky, in part fed by the Sharon drainage (fig. 35), became filled with coarse clastics. Primary distributaries of a developing delta (shown by "1" on fig. 35) aggraded, and the river began to spread its sediment through braided distributaries (shown by "2" on fig. 35) across most of southeastern Kentucky.

Detritus from the Appalachian metamorphic-source area, although mainly deposited in the axial portions of the subsiding Appalachian basin, was being carried increasingly farther west and northwest by streams that

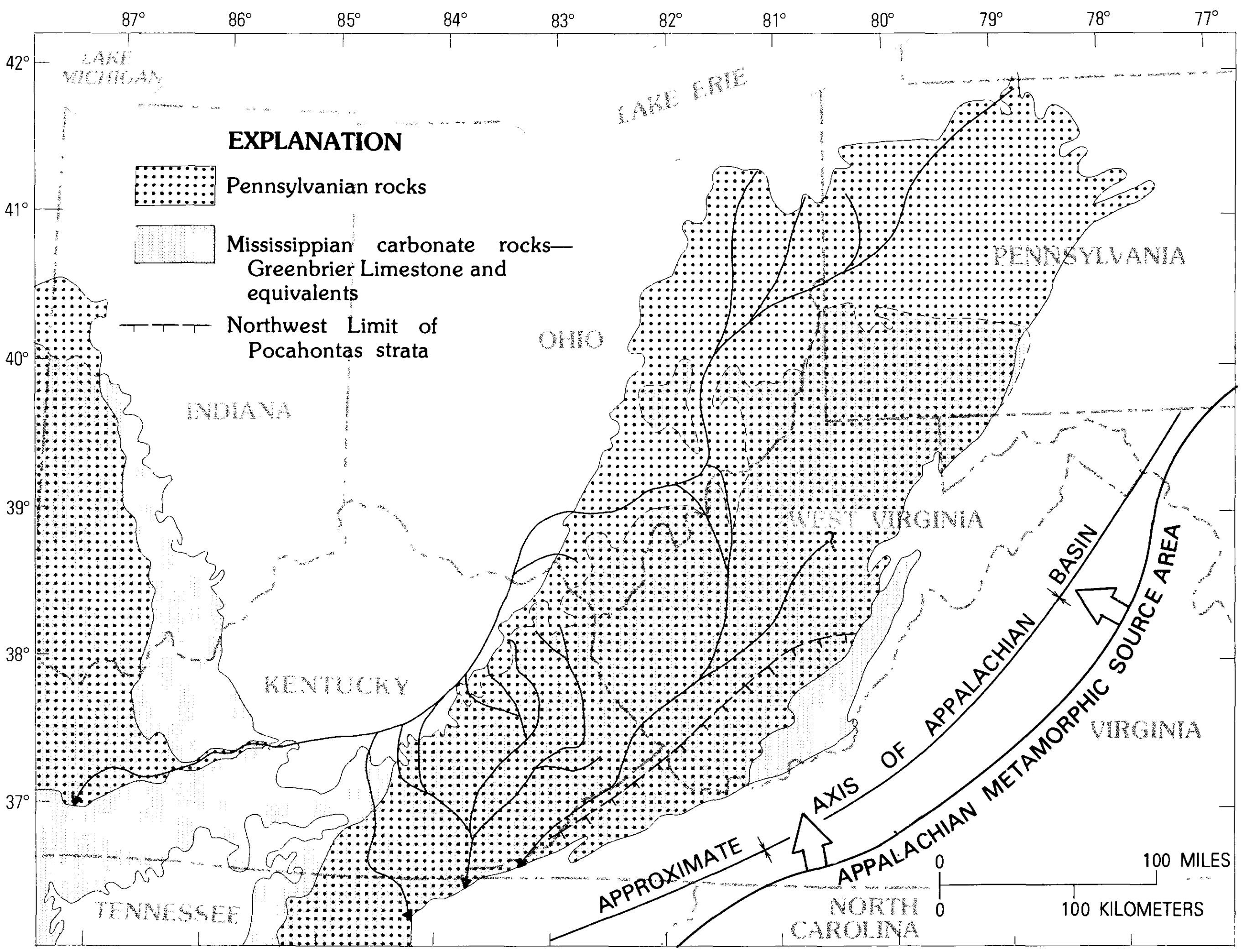


FIGURE 33.—Map of Kentucky, Ohio, West Virginia, and parts of adjacent states showing breaching of the drainage divide between the Appalachian and Eastern Interior basins during Early Pennsylvanian time. Western limit of Pocahontas strata from Englund and Henry (written commun., 1980).

at times became tributary to the southwest-flowing river. This merging of the two drainage systems gave rise to the lateral gradation and interlayering of quartzose sandstone with subgraywacke, siltstone, and shale in areas in southwestern Virginia and eastern Kentucky and to the deposition of the Hensley Member of the Lee Formation at the end of this stage. The facies relations of the deposits formed by the merging of the river systems are well illustrated by Miller (1974, p. 120, fig. 58). However, he interprets the quartzose sandstone facies of the Lee Formation, here as much as 1,000 ft thick, as beach and barrier island deposits. Lagoons, tidal and delta swamps are inferred to lie to the southeast and the sea to the northwest (Miller, 1974, p. 123, fig. 59). No marine deposits matching the scale of the inferred beaches and barrier islands are present in the Lower Pennsylvanian rocks of Kentucky. On the contrary, the available stratigraphic data generally indicate terrestrial environments in areas lateral to and northwest of that studied by Miller. Merging of the two drainage systems appears to be also responsible for the progressive reduction of the percentage of monocrystalline quartz pebbles (from northern cratonic sources) to polycrystalline quartz pebbles (from eastern metamorphic sources) in Lee and equivalent rocks southwestward from West Virginia to Tennessee (BeMent, 1976, p. 111).

In south central Ohio, swamps formed along the flood plain of the beheaded Sharon-Brownsville River leading to the formation of the Sharon coal bed. A thin shale immediately above this coal bed contains brackish to marine fossils, showing that, as a result of subsidence,

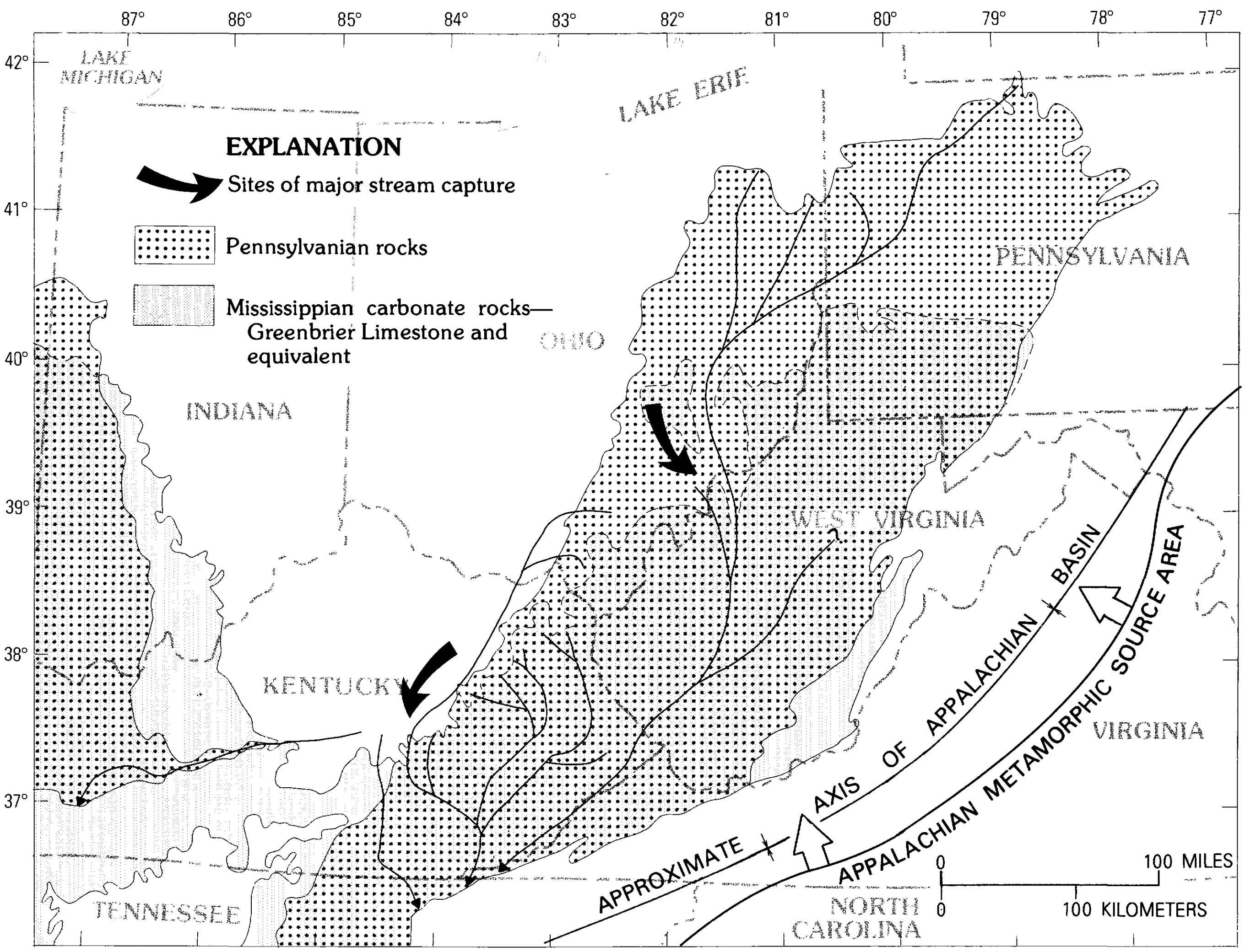


FIGURE 34.—Map of Kentucky, Ohio, and West Virginia, and parts of adjacent states showing changes in the drainage pattern following major stream captures in Early Pennsylvanian time.

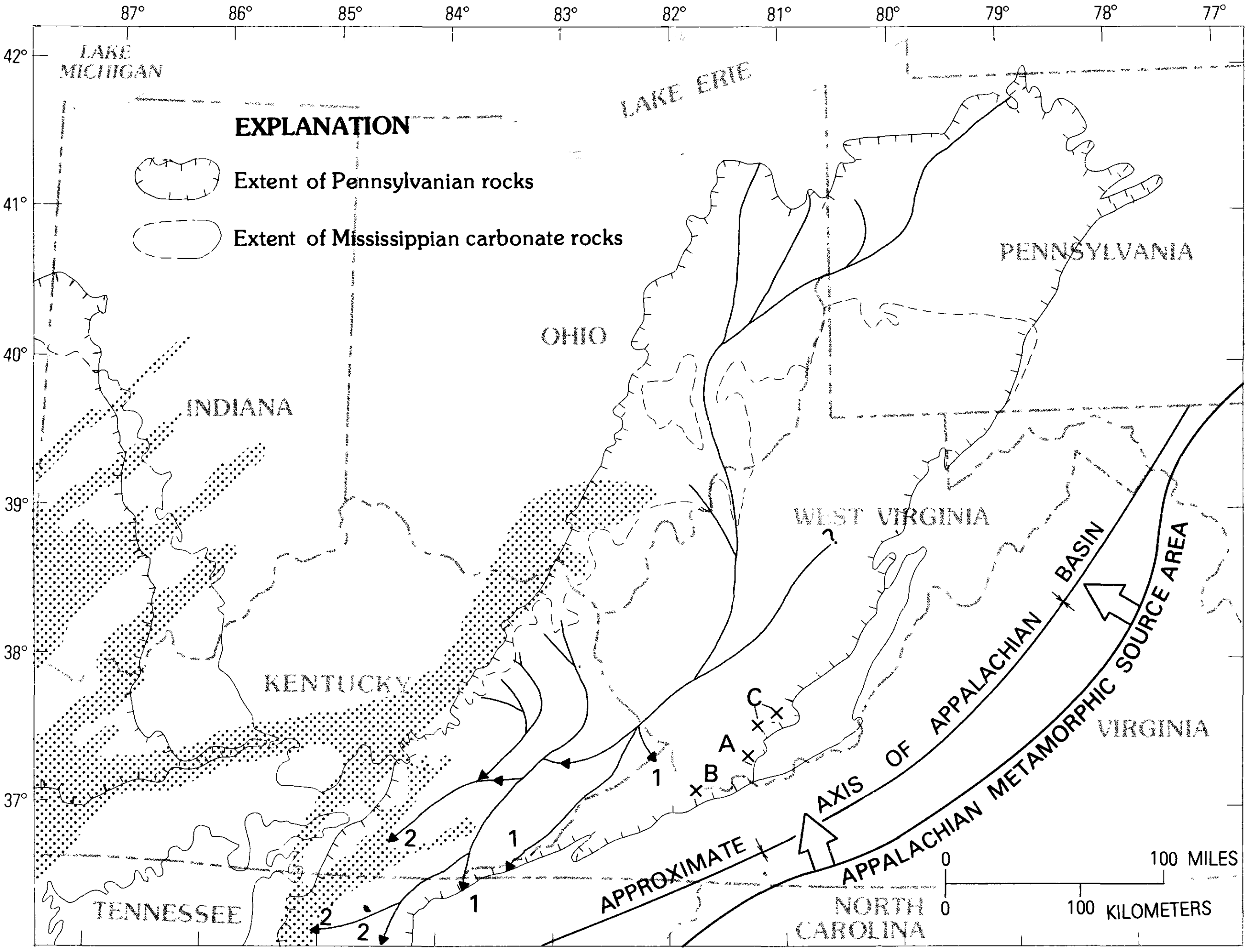


FIGURE 35.—Map of Kentucky, Ohio, and parts of adjacent states showing westward migration of major distributaries accompanied by aggradation in eastern Kentucky in later Early Pennsylvanian time; original distributaries are indicated by "1"; later distributaries by "2". The distribution of an Early Pennsylvanian shallow marine transgression is shown by stippled pattern west of and along the western margin of the Appalachian basin. Three marine to brackish horizons of Early Pennsylvanian age have been identified in parts of Virginia and West Virginia (Gordon and Henry, 1981); these are, with their location (shown by "X") and stratigraphic position: A, lower Pocahontas Formation (brackish water fauna); B, base of New River Formation (marine fauna); and C, middle New River Formation (marine fauna). The uppermost of those horizons east of Kentucky (C) may be about the same stratigraphic position as the marine unit shown by stippled pattern.

marine water from the west and southwest invaded parts of the river valley. Figure 35 shows the inferred extent of the marine transgression in parts of the Eastern Interior basin and the western part of the Appalachian basin. Brackish and marine water formed a shallow elongate bay that extended from near the edge of the Pottsville Escarpment in Tennessee to perhaps as far as 80 mi to the northeast in Kentucky as evidenced by a persistent marine zone in a coal and shale sequence in the Lower Pennsylvanian rocks below the Rockcastle Conglomerate Member of the Lee Formation. The transgression of marine water northwest and southeast of the Mississippian carbonate cuesta ended transportation of coarse clastics from the area of the Cincinnati Arch into the Appalachian basin.

Stage 5.—During stage 5, the area west of the Sharon River in south-central Ohio and northeastern Kentucky was alluviated mostly with silt and clay which formed a broad swampy plain. The higher portions of the cuesta of Mississippian carbonates remained above the alluvial plain. The water gap on the Ohio–West Virginia border continued to channel the Sharon drainage into central West Virginia and then southwestward into eastern Kentucky where coarse clastics continued to be deposited.

Stage 6.—At the beginning of stage 6, a slight upwarping of the alluvial plain along the axis of the Waverly Arch west of the Sharon River in south-central Ohio and northeastern Kentucky brought about intense leaching and kaolinization of siltstone and shale underlying swampy areas. In the same area, iron that was leached from overlying sediments was locally deposited as in iron carbonate replacement at the top of the Newman Limestone.

During this stage, deposition of the Naese Sandstone Member (now exposed in the Cumberland overthrust sheet) and its equivalent, the Rockcastle Conglomerate Member, on the southwestern margin of the Appalachian basin was completed. Source areas for these sediments northeast of West Virginia were either eliminated by regional subsidence or by masking deposits of the delta advancing from the east and southeast.

Stage 7.—During stage 7, there was renewed uplift near the headwaters of the Sharon drainage system, and the volume of coarse sediments and the size of streams were increased. In the area west of the Sharon drainage system, clay beds and overlying swamp deposits were locally dissected by rejuvenated streams. During this time, most of the Appalachian basin southeast of the cuesta of Mississippian carbonates was dominated by the delta extending westward and northwestward from the central Appalachian orogenic belt.

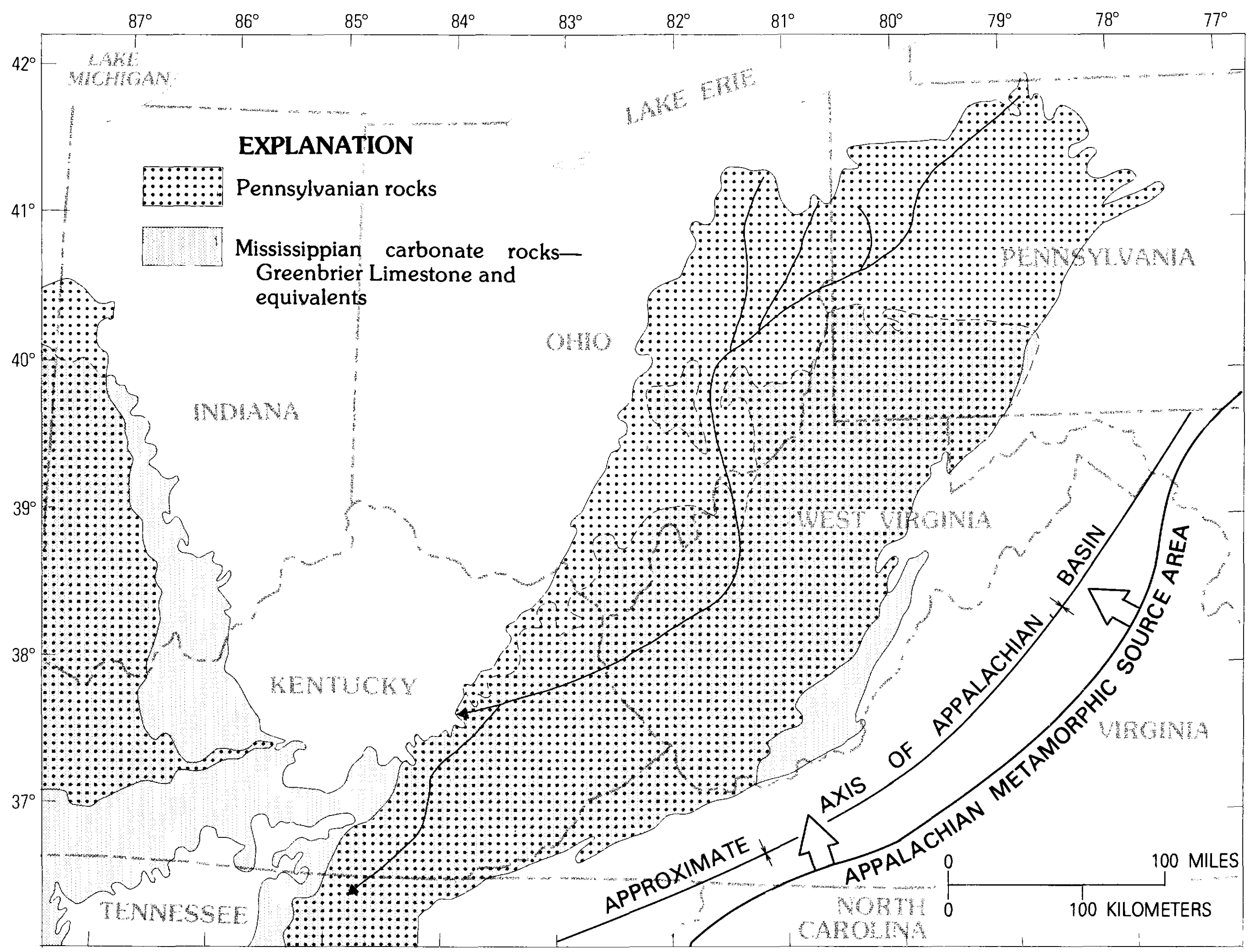


FIGURE 36.—Map of Kentucky, Ohio, West Virginia, and parts of adjacent states showing configuration of the Sharon drainage system in early Middle Pennsylvanian time.

Coarse clastics carried by the Sharon River into central West Virginia were diverted to the southwest along the Irving–Paint Creek and Kentucky River fault zones in Kentucky (fig. 36; see also fig. 7). Local marked differences of thickness of sandstone units on opposite sides of the faults indicate possible movements of the faults in Middle Pennsylvanian time (Short, 1978, p. 36).

Stage 8.—During stage 8, aggradation of streams in the northern and central Appalachian basin accompanied regional subsidence. As a result of uplift and increased erosion in its source area, the Sharon River again became braided and began to deposit broad sheets of pebbly sand and gravel. The Corbin Sandstone Member was deposited in Kentucky and the Massillon or Lower Connoquenessing equivalent sandstone members in Ohio and Pennsylvania. As regional subsidence continued in the central Appalachian basin, the Sharon-Corbin drainage system south of central Ohio was abandoned. The delta plain, which now extended westward across all of eastern Kentucky, was covered largely by swamps and lakes. The remnants of the Mississippian carbonate cuesta in northwestern West Virginia and northeastern Kentucky were buried beneath the apron of the delta. Continued subsidence led to the spread of marine water from the southwest across much of eastern Kentucky into West Virginia and was accompanied by deposition of a thin unnamed marine shale (Rice and Smith, 1980).

A brief renewal of the Sharon drainage system at a later time is indicated by the deposition of the Grayson sandstone bed at the northernmost end of the Lee outcrop belt in northeastern Kentucky (fig. 17). The filling of the southwest-trending Grayson channel with quartz-pebble sand and gravel concluded Lee deposition in eastern Kentucky.

PROBLEMS RELATED TO THE LEE FORMATION DESERVING FURTHER STUDY

Many interesting problems have arisen concerning the Lee Formation as a result of the mapping program. In some areas, mapping was completed before a regional stratigraphic framework was established and in other areas, members were incorrectly projected. Stratigraphic relations between the strata of the Lee Formation in the three outcrop belts were never clearly developed because subsurface studies were not generally included as part of the mapping program. Therefore, revision of the mapping done in the early part of the Kentucky mapping program on the basis of data developed in the later part of the program would be helpful. The following is a list of those major problems that could not be dealt with adequately in this summary because of insufficient data.

1. Lee-type sandstone units in the middle and upper parts of the Pennington Formation should be studied in Kentucky with regard to their stratigraphic position, thickness, and distribution, and should be related to formally named units. Many of these sandstone units are currently known only by names used informally by drillers. A study of these units should relate subsurface data to outcrop data along Pine and Cumberland Mountains so that petrology and sedimentary structures can be used for analyses of depositional environments and a better understanding of Upper Mississippian stratigraphy.
2. Similar studies of the members of the Lee Formation that are Mississippian in age, the Pinnacle Overlook, Chadwell, and White Rocks Members, should be conducted to determine their distributions, sources, and environments of deposition.
3. Extensive paleontological studies of marine units and coal beds and other plant-bearing strata should be conducted in the vicinity of the Mississippian-Pennsylvanian systemic boundary to determine the relations of the two systems.
4. A more detailed study of the inferred basal Pennsylvanian channel deposits (fig. 32) is warranted to determine their morphology and confirm their character.
5. A direct comparison of the petrology of basal Pennsylvanian sandstone and conglomerate units should be made to relate clastic sources in different parts of the central Appalachian basin at the beginning of Pennsylvanian time. Vertical and horizontal petrographic variations that involve relative proportions of mono- and polycrystalline quartz grains and pebbles as well as heavy mineral suites should be related to sedimentary structures in order to determine clastic sources and the evolution of the Lee deposits.
6. The Middlesboro Member should be restudied in the surface and subsurface in order to resolve the nomenclatural problems along Pine Mountain. The existence of the paleovalleys indicated on the thickness map of the Middlesboro Member (fig. 13) should be verified—investigation of the paleovalley just west of Rocky Face fault on Pine Mountain should help determine the reasons for the large differences in thickness of both Upper Mississippian and Lower Pennsylvanian units on opposite sides of the fault and should help determine the age and stratigraphic position on Pine Mountain of sandstone member A in the Middlesboro North quadrangle (Englund and others, 1964) or the lower part of the Middlesboro(?) Member in the Kayjay quadrangle (Rice and Maughan, 1978).

7. Insufficient thickness data for the Bee Rock and Naese Sandstone Members do not permit construction of separate isopach maps. These members are locally difficult to separate and may intertongue in a complex way with the overlying Hance Formation. Subsurface studies would help to clarify the identity of these members across Cumberland overthrust sheet and along Pine Mountain where they have been interpreted differently in the GQ reports.
8. The Rockcastle Conglomerate Member should be carefully delineated in Kentucky and its distribution, thickness, petrology, and sedimentary structures studied. The relation of this member of the Lee Formation to the Rockcastle Conglomerate of the Crab Orchard Mountains Group in Tennessee should be clarified and described.
9. The Corbin Sandstone Member should be carefully mapped from its type area to the Kentucky-Tennessee border so that it can be related to stratigraphic units mapped in Tennessee.

REFERENCES CITED

Alvord, D. C., 1971, Geologic map of the Hellier quadrangle, Kentucky-Virginia and part of the Clintwood quadrangle, Pike County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–950.

Alvord, D. C., and Miller, R. L., 1972, Geologic map of the Elkhorn City quadrangle, Kentucky-Virginia, and part of the Harman quadrangle, Pike County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–951.

Anderson, R. W., and Hester, N. C., 1977, Pennington Formation and Lower Tongue of the Breathitt Formation *in* Stratigraphic evidence for Late Paleozoic tectonism in northeastern Kentucky: American Association of Petroleum Geologists field guidebook for October 9, 1976, Lexington, Kentucky; published by Kentucky Geological Survey, Lexington, Kentucky, p. 29–35.

Ashley, G. H., and Glenn, L. C., 1906, Geology and mineral resources of part of the Cumberland Gap coal field, Kentucky: U.S. Geological Survey Professional Paper 49, 239 p.

BeMent, W. O., 1976, Sedimentological aspects of Middle Carboniferous sandstones on the Cumberland overthrust sheet: unpublished Ph. D. thesis, University of Cincinnati, Cincinnati, Ohio, 182 p.

Black, D. F. B., 1977, Geologic map of the Heidelberg quadrangle, east-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–1340.

Blancher, Donald, 1970, Origin of the Hazel Patch Sandstone Member of the Lee Formation of southeast Kentucky: unpublished M.S. thesis, University of Kentucky, Lexington, Kentucky.

Braun, E. L., 1950, Deciduous forests of eastern North America: Philadelphia, Blakiston, 596 p.

Bristol, H. M., and Howard, R. H., 1971, Paleogeologic map of the sub-Pennsylvanian Chesterian (Upper Mississippian) surface in the Illinois basin: Illinois State Geological Survey Circular 458, 13 p.

Burroughs, W. G., 1923, A Pottsville-filled channel in the Mississippian: Kentucky Geological Survey, ser. 6, v. 10, p. 115–126.

Campbell, M. R., 1893, Geology of the Big Stone Gap coal field in Virginia and Kentucky: U.S. Geological Survey Bulletin 111, 106 p.

——1896, Description of the Pocahontas quadrangle [Virginia-West Virginia]: U.S. Geological Survey Geologic Atlas, Folio 26.

——1898a, Description of the Richmond quadrangle [Ky]: U.S. Geological Survey Geologic Atlas, Folio 46.

——1898b, Description of the London quadrangle [Ky]: U.S. Geological Survey Geologic Atlas, Folio 47.

Coogan, A. H., Feldman, R. M., Szmac, E. J., and Mrakovich, J. V., 1974, Sedimentary environments of the Lower Pennsylvanian Sharon Conglomerate near Akron, Ohio *in* Selected field trips in northeastern Ohio, Guidebook no. 2, Division of Geological Survey, Columbus, Ohio, p. 21–41.

Coskren, T. D., and Rice, C. L., 1979, Contour map of the base of the Pennsylvanian System, eastern Kentucky: U.S. Geological Survey Miscellaneous Field Studies Map MF–1100.

Couchot, M. L., 1972, Paleodrainage and lithofacies relationships of the Sharon conglomerate of southern Ohio: unpublished M.S. thesis, Ohio University, Athens, Ohio.

Craig, L. C., and Connor, C. W., 1979, Paleotectonic investigations of the Mississippian System in the United States: U.S. Geological Survey Professional Paper 1010.

Csejtey, Bela, Jr., 1970, Geologic map of the Nolansburg quadrangle, southeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–868.

——1971, Geologic map of the Bledsoe quadrangle, southeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ–889.

Curray, J. R., 1956, The analysis of two-dimensional orientation data: Journal of Geology, v. 64, p. 117–131.

DeLaney, A. O., and Englund, K. J., 1973, Geologic map of the Ault quadrangle, northeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1066.

Dever, G. R., Jr., 1980, Stratigraphic relationships in the lower and middle Newman Limestone (Mississippian), east-central and northeastern Kentucky: Kentucky Geological Survey Thesis Series 1, 49 p. [Lexington, University of Kentucky M.S. Thesis, 1973, 121 p.].

Dever, G. R., Jr., and others, 1977, Stratigraphic evidence for Late Paleozoic tectonism in northeastern Kentucky—Field trip, Fifth Annual Meeting, Eastern Section, American Association of Petroleum Geologists, Lexington, Kentucky, October 9, 1976: Lexington, Kentucky Geological Survey, 80 p.

de Witt, Wallace, Jr., and McGraw, L. W., 1979, Appalachian basin region *in* Paleotectonic investigations of the Mississippian System in the United States, [pt. 1], coordinators Lawrence C. Craig and Carol Waite Connor: U.S. Geological Survey Professional Paper 1010, p. 13–48.

Englund, K. J., 1964a, In the Cumberland Mountains of southeastern Kentucky stratigraphy of the Lee Formation: U.S. Geological Survey Professional Paper 501-B., p. B30–B38.

——1964b, Geology of the Middlesboro South quadrangle, Tennessee-Kentucky-Virginia: U.S. Geological Survey Geologic Quadrangle Map GQ-301.

——1968, Geology and coal resources of the Elk Valley area, Tennessee and Kentucky: U.S. Geological Survey Professional Paper 572, 59 p.

——1972, Central Appalachian tectonics as indicated by structural features in Carboniferous rocks (abs.): American Association of Petroleum Geologists Bulletin, v. 56, no. 10.

——1974, Sandstone distribution patterns in the Pocahontas Formation of southwest Virginia and southern West Virginia, *in* Briggs, Garret, ed., Carboniferous of the southeastern United

States: Geological Society of America Special Paper 148, p. 31–45.

———1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Virginia: U.S. Geological Survey Professional Paper 1110-C, 21 p.

Englund, K. J., Arndt, H. H., and Henry, T. W., 1979, Proposed Pennsylvanian System Stratotype, Virginia and West Virginia: American Geological Institute Selected Guidebook Series No. 1, 138 p.

Englund, K. J., and DeLaney, A. O., 1966, Intertonguing relations of the Lee Formation in southwestern Virginia: U.S. Geological Survey Professional Paper 550-D, p. D47–D52.

Englund, K. J., Landis, E. R., and Smith, H. L., 1963, Geology of the Varilla quadrangle, Kentucky-Virginia: U.S. Geological Survey Geologic Quadrangle Map GQ-190.

Englund, K. J., Roen, J. B., and DeLaney, A. O., 1964, Geology of the Middlesboro North quadrangle, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-300.

Englund, K. J., and Smith, H. L., 1960, Intertonguing and lateral gradation between the Pennington and Lee Formations in the tri-state area of Kentucky, Tennessee, and Virginia [abs.]: Geological Society of America Bulletin, v. 71, no. 12, pt. 2, p. 2015.

Englund, K. J., Smith, H. L., Harris, L. D., and Stephens, J. G., 1963, Geology of the Ewing quadrangle, Kentucky and Virginia: U.S. Geological Survey Bulletin 1142-B, 23 p.

Englund, K. J., and Windolph, J. F., Jr., 1971, Geology of the Carter Caves Sandstone (Mississippian) in northeastern Kentucky: U.S. Geological Survey Professional Paper 750-D, p. D99–D104.

———1975, Geologic map of the Olive Hill quadrangle, northeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1270.

Ettensohn, F. R., 1977, Effects of synsedimentary tectonic activity on the upper Newman Limestone and Pennington Formation, *in* Dever, G. R., Jr., and others, Stratigraphic evidence for late Paleozoic tectonism in northeastern Kentucky—Field trip Fifth Annual Meeting, Eastern Section, American Association of Petroleum Geologists, Lexington, Kentucky, October 9, 1976: Lexington, Kentucky Geological Survey, p. 18–29.

———1979, The barrier-shoreline model in northeastern Kentucky *in* Ettensohn, F. R. and Dever, G. R., Jr., ed., Carboniferous geology from the Appalachian basin to the Illinois basin through eastern Ohio and Kentucky edited by Frank R. Ettensohn and Garland R. Dever, Jr.-Lexington: University of Kentucky, 1979, p. 124–129.

Ferm, J. C., 1974, Carboniferous environmental models in eastern United States and their significance, *in* Briggs, Garrett, ed., Carboniferous of the southeastern United States: Geological Society of America Special Paper 148, p. 79–95.

Ferm, J. C., Horne, J. C., Swinchatt, J. P., and Whaley, P. W., 1971, Carboniferous depositional environments in northeastern Kentucky—Geological Society of Kentucky, Guidebook for annual spring field conference, April 1971: Lexington, Kentucky Geological Survey, 30 p.

Ferm, J. C., Milici, R. C., and Eason, J. E., 1972, Carboniferous depositional environments in the Cumberland Plateau of southern Tennessee and northern Alabama: Tennessee Division of Geology Report of Investigations No. 33, 32 p.

Flowers, R. R., 1956, A subsurface study of the Greenbrier Limestone in West Virginia: West Virginia Geology and Economic Survey Report of Investigations 15, 17 p.

Froelich, A. J., 1972, Geologic map of the Wallins Creek quadrangle, Harlan and Bell Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1016.

———1973, Geologic map of the Louellen quadrangle, southeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1060.

Froelich, A. J., and Stone, B. D., 1973, Geologic map of parts of the Benham and Appalachia quadrangles, Harlan and Letcher Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1059.

Froelich, A. J., and Tazelaar, J. F., 1973, Geologic map of the Balkan quadrangle, Bell and Harlan Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1127.

———1974, Geologic map of the Pineville quadrangle, Bell and Knox Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1129.

Fuller, J. O., 1955, Source of Sharon Conglomerate of northeastern Ohio: Geological Society of America, v. 66, p. 159–176.

Gordon, Mackenzie, Jr., and Henry, T. W., 1981, Late Mississippian and Early Pennsylvanian invertebrate faunas, east-central Appalachians—A preliminary report *in* Roberts, T. G., ed., Cincinnati '81 Field Trip Guidebooks,v. 1: Geological Society of America, p. 165–171.

Haney, D. C., 1979, The Mississippian-Pennsylvanian systemic boundary in eastern Kentucky: Southeastern Geology, v. 21, No. 1, p. 53–62.

Haney, D. C. and Rice, C. L., 1978, Geologic map of the Leighton quadrangle, east-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1495.

Hayes, P. T., and Connor, C. W., 1982, Coal geology of Adams, Blaine, Richardson, and Sitka quadrangles, Kentucky, and Louisa quadrangle, Kentucky-West Virginia: U.S. Geological Survey Bulletin 1526, 68 p.

Hoge, H. P., 1977, Geologic map of the Frenchburg quadrangle, east-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1390.

Horne, J. C., 1979, The orthoquartzite problem, *in* Ferm, J. C., and others, eds., Carboniferous depositional environments in the Appalachian region [Collected papers] Columbia, S. C., University of South Carolina, p. 370.

Horne, J. C., and Ferm, J. C., 1970, Facies relationships of the Mississippian-Pennsylvanian contact in northeastern Kentucky [abs.] Geological Society of America Abstracts with Programs, v. 2, No. 3, p. 217.

Horne, J. C., Ferm, J. C., and Swinchatt, J. P., 1974, Depositional model for the Mississippian-Pennsylvanian boundary in northeastern Kentucky, *in* Briggs, Garrett, ed., Carboniferous of the southeastern United States: Geological Society of America Special Paper 148, p. 97–114.

Horne, J. C., Swinchatt, J. P., and Ferm, J. C., 1971, Lee-Newman barrier shoreline model, *in* Ferm and others, Carboniferous depositional environments in northeastern Kentucky—Geological Society of Kentucky, Guidebook for annual spring field conference, April 1971: Lexington, Kentucky Geological Survey, p. 5–9.

Houseknecht, D. W., 1978, Petrology and stratigraphy of some Pottsville quartzites and graywackes of West Virginia: unpublished Ph.D. thesis, Pennsylvania State University, University Park, Pa.

Lamborn, R. E., 1945, Recent information on the Maxville Limestone: Geological Survey of Ohio, Series 4, Information Circular No. 3, 18 p.

Lobeck, A. K., 1929, The geology and physiography of the Mammoth Cave National Park: Kentucky Geological Survey, ser. 6, v. 31, pt. 5, p. 327–399.

Loney, R. A., 1967, Geologic map of the Hollyhill quadrangle, McCreary, and Whitley Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-615.

Maughan, E. K., 1976, Geologic map of the Roxana quadrangle, Letcher and Harlan Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1299.

McDowell, R. C., 1978, Geologic map of the Levee quadrangle, east-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1478.

McDowell, R. C., Peck, J. H., and Mytton, J. W., 1971, Geologic map of the Plummers Landing quadrangle, Fleming and Rowan Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-964.

Meckel, L. D., 1967, Origin of Pottsville conglomerate (Pennsylvanian) in the central Appalachians: Geological Society of America Bulletin, v. 78, no. 2, p. 223–258.

———1970, Paleozoic alluvial deposition in the central Appalachians-A summary, *in* Fisher, G. W., Pettijohn, F. J., Reed, J. C., Jr., and Weaver, K. N., eds., Studies of Appalachian geology-Central and southern: New York, Interscience, p. 49–67.

Milici, R. C., Briggs, Garrett, Knox, L. M., Sitterly, P. D., and Statler, A. T., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Tennessee: U.S. Geological Survey Professional Paper 1110-G, 38 p.

Miller, A. M., 1908, Abstract of a report on the lower (or "conglomerate") measures along the western border of the eastern coal fields: Kentucky Geological Survey Report of Progress, 1906–1907, p. 27–35.

———1910, Coals of the lower measures along the western border of the eastern coal field: Kentucky Geological Survey Bulletin 12, 83 p.

Miller, M. S., 1974, Stratigraphy and coal beds of Upper Mississippian and Lower Pennsylvanian rocks in southwestern Virginia: Virginia Division of Mineral Resources, Bulletin 84, 211 p.

Miller, R. L., 1969, Pennsylvanian formations of southwest Virginia: U.S. Geological Survey Bulletin 1280, 62 p.

Miller, R. L., and Roen, J. B., 1973, Geologic map of the Pennington Gap quadrangle, Lee County, Virginia, and Harlan County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1098.

Mrakovich, J. V., 1969, Fluvial deposits of the Sharon Conglomerate in Portage, Summit, eastern Medina and northeastern Wayne Counties: unpublished M.S. thesis, Kent State University, Kent, Ohio.

Phalen, W. C., 1912, Description of the Kenova quadrangle [Kentucky-West Virginia-Ohio]: U.S. Geological Survey Geologic Atlas, Folio 184.

Philley, J. C., Hylbert, D.K., and Hoge, H. P., 1974, Geologic map of the Cranston quadrangle, northeastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1212.

Potter, P. E., and Siever, Raymond, 1956a, Cross-bedding, [Pt.] 1 *of* Sources of basal Pennsylvanian sediments in the Eastern Interior basin: Journal of Geology, v. 64, No. 3, p. 225–244.

———1956b, Some methodological implications, [Pt.] 3 *of* Sources of basal Pennsylvanian sediments in the Eastern Interior basin: Journal of Geology, v. 64, No. 5, p. 447–455.

Pryor, W. A., and Potter, P. E., 1979, Sedimentology of a paleovalley fill: Pennsylvanian Kyrock Sandstone in Edmonson and Hart Counties, Kentucky, *in* Palmer, J. E., and Dutcher, R. R., ed., Depositional and structural history of the Illinois basin, Part 2: Invited Papers Illinois State Geological Survey, p. 49–65.

Pryor, W. A., and Sable, E. G., 1974, Carboniferous of the Eastern Interior basin, *in* Briggs, Garrett, eds., Carboniferous of the southeastern United States: Geological Society of America Special Paper 148, p. 281–313.

Rice, C. L., 1968, Geologic map of the Redbush quadrangle, eastern Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-708.

———1972, Geologic map of the Alcorn quadrangle, east-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-963.

———1973, Geologic map of the Jenkins West quadrangle, Kentucky-Virginia: U.S. Geological Survey Geologic Quadrangle Map GQ-1126.

———1978, The ages of the Lee, Breathitt, Caseyville, Tradewater, and Sturgis Formations in Kentucky, *in* Sohl, N. F., and Wright, W. B., 1977, Changes in stratigraphic nomenclature by the U.S. Geological Survey: U.S. Geological Survey Bulletin 1457-A, p. 108–109.

Rice, C. L., and Haney, D. C., 1980, The Mississippian-Pennsylvanian systemic boundary in eastern Kentucky—Discussion and Reply: Southeastern Geology, v. 21, no. 4, p. 299–305.

Rice, C. L., and Maughan, E. K., 1978, Geologic map of the Kayjay quadrangle and part of the Fork Ridge quadrangle, Bell and Knox Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1505.

Rice, C. L., and Newell, W. L., 1975, Geologic map of the Saxton quadrangle and part of the Jellico East quadrangle, Whitley County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1264.

Rice, C. L., Sable, E. G., Dever, G. R., Jr., and Kehn, T. M., 1979, The Mississippian and Pennsylvanian (Carboniferous) Systems in the United States—Kentucky: U.S. Geological Survey Professional Paper 1110-F, 32 p.

Rice, C. L., and Smith, J. H., 1980, Correlation of coal beds, coal zones, and key stratigraphic units in the Pennsylvanian rocks of eastern Kentucky: U.S. Geological Survey Miscellaneous Field Studies Map MF-1188.

Rice, C. L., and Wolcott, D. E., 1973, Geologic map of the Whitesburg quadrangle, Kentucky-Virginia, and part of the Flat Gap quadrangle, Letcher County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1119.

Sheppard, R. A., 1964, Geology of the Portsmouth quadrangle, Kentucky-Ohio, and parts of the Wheelersburg and New Boston quadrangles, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-312.

Short, M. R., 1978, Petrology of the Pennington and Lee Formations of northeastern Kentucky and the Sharon Conglomerate of southeastern Ohio: unpublished Ph.D. thesis, University of Cincinnati, Cincinnati, Ohio.

Siever, Raymond, and Potter, P. E., 1956, Sedimentary petrology, [Pt.] 2 of Sources of basal Pennsylvanian sediments in the Eastern Interior basin: Journal of Geology, v. 64, No. 4, p. 317–335.

Tazelaar, J. F., and Newell, W. L., 1974, Geologic map of the Evarts quadrangle and parts of the Hubbard Springs quadrangle, southeastern Kentucky and Virginia: U.S. Geological Survey Geologic Quadrangle Map GQ-914.

Wanless, H. R., 1939, Pennsylvanian correlations in the Eastern Interior and Appalachian coal fields: Geological Society of America Special Paper 17, 130 p.

———1946, Pennsylvanian geology of a part of the Southern Appalachian coal field: Geological Society of America Memoir 13, 162 p.

———1975a, Appalachian region, *in* McKee, E. D., and Crosby, E. J., coordinators, Introduction and regional analyses of the Pennsylvanian System, Pt. 1, of Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Professional Paper 853, pt. 1, p. 17–62.

———1975b, Illinois basin region, *in* McKee, E. D., and Crosby, E. J., coordinators, Introduction and regional analyses of the Pennsylvanian System, Pt. 1, of Paleotectonic investigations of the Pennsylvanian System in the United States: U.S. Geological Survey Professional Paper 853, pt. 1, p. 69–95.

Weir, G. W., 1974a, Geologic map of the Stanton quadrangle, Powell

County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1182.

——1974b, Geologic map of the Slade quadrangle, east-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1183.

——1975, Abandonment of the term Beattyville Shale (of the Lee Formation), *in* Cohee, G. V., and Wright, W. P., Changes in stratigraphic nomenclature by the U.S. Geological Survey: U.S. Geological Survey Bulletin 1395-A, p. A56–A59.

Weir, G. W., and Mumma, M. D., 1973, Geologic map of the McKee quadrangle, Jackson and Owsley Counties, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1125.

Weir, G. W., and Richards, P. W., 1974, Geologic map of the Pomeroyton quadrangle, east-central Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-1184.

White, I. C., 1885, Nomenclature of Appalachian coal beds: The Virginias, v. 6, p. 7–16.

Whittington, C. L., and Ferm, J. C., 1967, Geologic map of the Grayson quadrangle, Carter County, Kentucky: U.S. Geological Survey Geologic Quadrangle Map GQ-640.

Wilpolt, R. H., and Marden, D. W., 1959, Upper Mississippian rocks of southwestern Virginia, southern West Virginia, and eastern Kentucky: U.S. Geological Survey Oil and Gas Investigations Preliminary Chart 38, 3 sheets.

Wixted, J. B., 1977, Sedimentary aspects of the Livingston Conglomerate, southeastern Kentucky: unpublished M.S. thesis, University of Kentucky, Lexington, Ky.

Woodward, H. P., 1961, Preliminary subsurface study of southeastern Appalachian Interior Plateau: American Association of Petroleum Geologists Bulletin v. 45, p. 1634–1655.